A STUDY OF CORROSION IN

TURPENTINE-GUM PROCESSING UNITS

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A THESIS

Submitted in partial fulfillment
of the requirements for the Degree
of Master of Science in Chemical Engineering

by

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Georgia School of Technology
Atlanta, Georgia
1942

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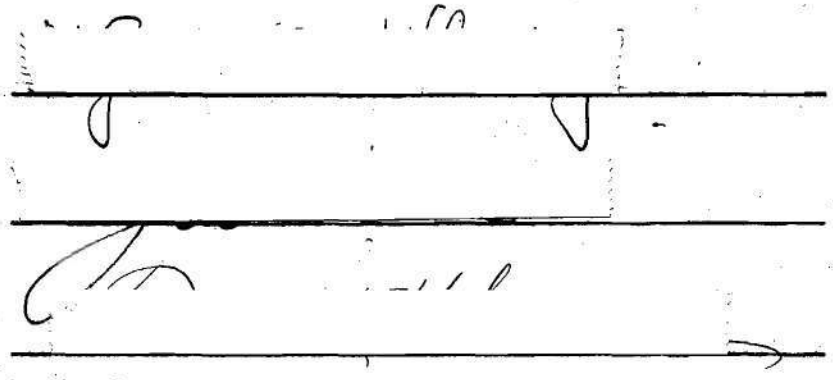
Approved:



Date Approved by Chairman May 7, 1942

ACKNOWLEDGMENTS

On completion of this work, I wish to thank Mr. L. D. Yates, formerly assistant professor of Chemical Engineering at the Georgia School of Technology, who directed the initial portion of this series of studies, and Dr. J. W. Mason who directed the latter portion. I wish to acknowledge Mr. W. Z. Friend of International Nickel Company, Inc., and Mr. C. L. Newman of Carnegie-Illinois Steel Corporation for their help in securing samples of the metals and alloys to be tested. Mr. Friend also gave invaluable suggestions in experimental technique for which I am grateful. I wish to thank Mr. G. P. Shingler, senior chemist of the Naval Stores Research Station at Olustee, Florida, for supplying the necessary turpentine-gum samples for the tests and for his close cooperation in every respect.

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NOTATIONS

Notation:

ipy.....Inches penetration per year

Copper Steel.....Copper bearing steel of low carbon content

Steel 302.....USS 18-8 stainless steel of high carbon content, Type 302

Steel 304.....USS 18-8 S stainless steel of low carbon content, Type 304

Steel 316.....USS 18-8 stainless steel containing molybdenum, Type 316

Steel 347.....USS 18-8 stainless steel containing columbium, Type 347

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INTRODUCTION

General Theory of Corrosion

Corrosion has long been a problem of industrial importance. The solution of this problem may often mean the difference between profit and loss.

It is now generally agreed that the most logical and elastic corrosion theory is the electrochemical theory first suggested by Whitney[1] and Walker[2] early in the twentieth century. This first hypothesis has since been enlarged and improved upon until now most corrosion phenomena can be explained[3].

There are many factors which influence the corrosion rate to a greater or lesser degree. The presence of oxygen is one of the most important factors. The rate as which dissolved oxygen can reach the metal surface determines the

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[1] W.R. Whitney, "The Corrosion of Iron", Journal of the American Chemical Society, Vol. 25, pp. 393-406, 1903.

[2] W.H. Walker, A.M.Cederholm, L.N. Brent, "The Corrosion of Iron and Steel", Ibid, Vol. 29, pp. 1251-1264, 1907.

[3] F.N. Speller, "A Study of Corrosion Factors and the Electrochemical Theory", Industrial and Engineering Chemistry, Vol. 17, pp. 348-354, 1925.

corrosion rate in most natural water corrosion. This rate depends on the rate of solution and diffusion, the oxygen content of the media, the temperature at which the corrosion occurs, the pressure and humidity of the air, the velocity of motion of the corroding media, the presence of surface films, the concentration of other dissolved substances, the viscosity of the solution, the depth of immersion of the metal, and the area of the corroding solution exposed to the air.

Other factors which influence corrosion but do not affect the oxygen supply are: Nernst's metal potential or solution pressure, the metal ion concentration in water, the pH of the solution, the unequal distribution on the metallic surface of the dissolved substances in the solution, the overvoltage of the hydrogen on the metal in electrical contact with it, the contact of the metal with other conducting substances, the character and uniformity of the surface finish, segregation of impurities in the metal, composition of the metal, the electrical potential applied externally to the metal, conductivity of the corroding solution, the action of light, presence of oxidizing agents, area of the metal exposed as the anode, the chemical content of the corroding solution, duration of exposure, passivity, and the existence of mechanical stresses in the metal. Some of these factors influence the quantity of corrosion while others influence only its distribution.

The factors which are involved in initial corrosion reactions are the "primary" factors[4]. Others enter in after corrosion has started and are termed "secondary" factors. These primary factors are subdivided:

(1) As affecting anodic reactions: The solution potential of the metal which depends on the place it occupies in the e. m. f. table and the concentration of the ion in the surrounding solution.

(2) As affecting cathodic reactions: the potential available for the deposition and the removal of hydrogen--the solution pressure of the metal.

The resultant of all these factors, both primary and secondary, determines the rate of corrosion in any particular case.

The solution pressure referred to previously is concerned with the definite tendency of metals to go into solution to form ions. This process maintains corrosion. Measurements have been made of this tendency and the electrochemical series is the result. Ordinarily any metal will displace any following if the ionic concentrations of the two are the same, but secondary factors may tend to interfere. By the application of an external e. m. f., the solution potentials can be overshadowed and the reaction either speeded up or driven in

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[4] W. S. Calcott and J.C. Whetzel, "Laboratory Corrosion Tests", Transactions of the American Institute of Chemical Engineers, Vol. 15, Part 1, pp. 1-114, 1923.

the opposite direction. The metal potential is decreased by raising the concentration of the ion in solution. This might retard corrosion, but in some cases, such as with iron, the ion concentration is limited in alkaline solutions by the solubility of the hydroxide.

The presence of electrically connected metals of high and low potentials and overvoltage respectively, such as iron and platinum, permits gas evolution from the more cathodic and hastens corrosion. Slag inclusions and mill scale on iron are practical cases of dissimilar conductors in contact with one another. When the metal is almost covered with inert cathodic conductor, smaller unprotected areas corrode rapidly if the solution has fairly good conductivity. The depth of pitting bears some relation to the ratio of anodic area exposed and cathodic area that is covered with protective coating.

Dissimilar solutions in contact with a metal may also cause pitting, or the same effect may be achieved by a solution of a single material in different concentrations. A current, however small, will flow from that portion of the metal in contact with the more dilute to that in contact with the more concentrated--the portion of metal in the dilute concentration becoming anodic and corroding by anodic solution.

Pitting, as a result of oxygen concentration cells has been explained by Evans[5] as follows:

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[5] U.S. Evans, "The Action of Salt Solution on Iron and Steel in the Presence of Oxygen", Journal of the Society of Chemical Industry, Vol. 43, pp. 315T-322T, 1924.

Suppose that a small cavity exists in the surface of the metal into which oxygen cannot diffuse quickly. A current will be produced between the unaerated area within the cavity, which will become anodic,and the aerated part of the surface outside which will be cathodic; a soluble salt will be formed at the anodic surface within the cavity but this will not interfere with further anodic attach. At the mouth of the cavity where the soluble salt formed on the interior mixes with the alkali from the cathodic portion outside, hydroxide may be precipitated, but it will not stop anodic solution within. Since the rate of attack is determined by the supply of oxygen to the whole surface outside the pit, and since it is all concentrated to small areas within the pits, the rate at which corrosion bores into the metal will be very great; and perforation may occur at this one point before any appreciable thinning has occurred at other parts of the surface.

Oxygen may have another function in the corrosion process--it may inhibit the rate of corrosion by the formation of a relatively impenetrable film of oxide, usually invisible, which makes the metal impervious to corrosion even in the presence of corrosive media. While this film usually forms almost instantaneously on exposure of a metal surface to air, the film is perhaps not as effective as when induced by oxidizing agents such as potassium dichromate. Such a condition is termed "passivity". This film, while resistant to corrosion, tends to cause localized corrosion of a greater rate if it happens to be broken. Pitting results by the mechanism mentioned above.

One is impressed by the large number of variables; but the problem is not as complicated as it might seem, for whereas each of the factors is undoubtedly important under certain conditions, there are wide ranges of conditions in

which comparatively few have any importance in influencing the rate of corrosion--that of others being negligible or zero. It is very important to distinguish between conditions in which various factors are controlling if results are to be uniform. One should stay within the same set of conditions for any particular experiment.

Corrosion Testing Methods

The methods of testing for corrosion are, it seems to me, not sufficiently standardized to the extent of enabling one to predict accurately the life of a metal serving a particular purpose. Searle and La Que[6], however, mention cases where predicted results check very closely with those found in actual operation. The tests that are usually run are speedy, comparative tests that give results for the metals under specified conditions. These metals might easily and probably will have different corrosion resisting properties in actual operation; however, since it would be practically impossible to test the countless metals and alloys for all the various uses to which they might be put, the tests are about the best possible substitute.

Specific tests include the salt spray test in which the metal being tested is jet-sprayed with a solution of

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[6]H.E. Searle and F.L. La Que, "Corrosion Testing Methods", American Society for Testing Materials, Vol. 35, Part 2, pp. 249-260, 1935.

three and one-half per cent salt in water; alternate immersion tests or continued immersion tests in which the sample is alternately dipped in a corroding solution of definite composition and then exposed to the air for a specified period or immersed continually in the corroding solution, as the case might be. The Myluis number depends on the temperature change of a ten per cent hydrochloric acid solution reacting on the sample. The number is given by the average increase in temperature between twenty degrees centigrade and the maximum temperature reached. Other such tests include measuring the volume of gas evolved per unit time when the metal is dissolved in a definite quantity of five per cent aqueous hydrochloric acid at twenty degrees centigrade.

If the tests appear to be faulty, the methods of interpreting them and of evaluating the corrosion losses may seem even more so. Most publications on corrosion measure the results by loss of weight and then, by knowing the dimensions of the sample, the density, etc., converting this weight loss to a similar relationship known as "inches penetration per year". An even simpler method consists of the inspection and comparison of the sample with uncorroded specimens of the same sample or with other materials used for the same purpose. This has the disadvantage of leaving no record by means of which one investigator can compare his work with that of another.

When the sample is weighed before and after the test, the data are specific but the disadvantage lies in the difficulty of carrying out the test satisfactorily. Frequently there are adherent products of corrosion which cannot be removed without removing, at the same time, some of the residual uncorroded material.

The products of corrosion may be determined analytically, but the results yielded can be used only when it is certain that all of the products of corrosion are available for analysis.

The depth to which corrosion has penetrated may be measured by removing the surface until this depth is reached. It is, however, difficult to measure this depth or to remove the surface satisfactorily.

The fallacy of the above methods is that they tell us nothing of the properties of the metal which is apparently unattacked, but which may have been subject to internal disruption and disintegration. Methods which may lead to erroneous generalizations should be avoided. Methods of appraising the damage done by corrosion must essentially depend upon the nature of the chemical and physical actions involved. Portevin[7] lists five principal modes which may be singled out:

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[7] A. Portevin, "Methods of Determining Effects of Corrosion", Metal Progress, Vol. 22, pp. 57-58, July , 1932.

(1) When the metal corrodes by uniform solution, it is reduced an equal amount over the entire area. In such cases it is logical to measure the effect by the loss of weight, or, better, the depth of corrosion.

(2) There is localized corrosion in pits or seams. The effect on the mechanical properties is not proportional to the loss in weight, since the pits act as notches and considerably reduce the capacity for deformation and consequently the elongation and contraction of area in a tension test. This kind of corrosion is a statistical phenomena. For the same loss in weight, a tank sheet may undergo superficial thinning when the corrosion belongs to class one or be useless owing to penetration when the corrosion belongs to class two.

(3) Subsurface corrosion may occur. This develops in depth and provokes either flaws or the chemical transformation of a constituent. A typical example is the "graphitization" of cast iron in sea water which in time transforms it into a product having no cohesion, when its appearance remains unaltered. A variation in weight is evidently of no use in measuring this phenomena.

(4) There may be corrosion cracking. Under the influence of particular reagents, some metals and alloys spontaneously crack, and the cracks are propagated between the crystalline grains. The metal has lost its resistance, but there is no relation between loss in weight and

deterioration. Such an alteration in properties is not easily detected. About the only method to test is the qualitative one of striking the piece and listening to the note it gives out. An unattacked sheet is sonorous while an attacked one has a hollow, dead sound.

(5) Corrosion may cause specific brittleness in the metal sample. Sometimes some specific property of the metal may be altered by the external chemical influence without loss in weight--the brittleness of mild steel induced by the chemical influences which evolve atomic hydrogen.

Naval Stores

Naval stores means turpentine and rosin and comes from the gum of certain species of pine trees--the kind of pines that grow in the Southern States. For more than a century the South has been the world's largest producer of naval stores. Naval stores is of national importance because its products are used in the manufacture of so many articles. It is important to the South because it employs many people, is an annual crop worth millions, and yields returns from lands that grow pine trees better than they do other crops. It is our most important export in the chemical field. More than half of the total production is exported.

The naval stores industry originated in Nova Scotia in 1606. It has changed its name from "turpentine farming" to "naval stores industry", and its original purpose from providing pitch and pine tar for calking ships to supplying

rosin and turpentine for everyday use.

The principal use of rosin[8] is in sizing paper. Another major use is in making varnishes. Rosin gives soap desirable properties and prevents it from softening in warm weather. It is used in making printing ink. There is rosin in linoleum, in sealing wax, in rubber goods, greases, and insulating compounds.

The main use for turpentine[9] is that of a thinner for paints and varnishes. It serves as the raw material for making synthetic camphor, some synthetic perfumes, and finds use in various pharmaceutical and chemical preparations. Turpentine has a place in the medicine cabinet of almost every home in the land.

The Naval Stores Research Division of the United States Department of Agriculture, Bureau of Chemistry and Soils, has as its primary object the development of more economical and efficient methods for the refining of the turpentine and gum in order that some of the tremendous losses that occur in the industry may be greatly reduced--the present loss in turpentine and rosin is some over six million dollars a year on a forty million dollar crop. The most recent finding in the naval stores work, and now being developed to a practical basis, is a method for making, from ordinary gum, a rosin

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[8]Jesse O. Reed, "Upgrading Oleoresin by a New Process", Chemical and Metallurgical Engineering, 48:70, December, 1941.

[9]Loc. cit..

product that is seven grades higher than the highest of the thirteen American standard grades. The station has made available to the producer, at his own still, the best practices in still operation.

Corrosion has long been a major problem with the naval stores work. Personnel at the Naval Stores Research Station in Olustee, Florida, were anxious that this study be made, for they are finding a great many calls made on them to recommend the best materials to be used in still construction and gum refinement. With the patenting[10] of their gum cleaning process, a greater need has come for equipment to conduct properly the processing.

Gum Cleaning Process

In processing pine gum, oleoresin from the trees is poured into the melter and diluted with turpentine to a total turpentine content of forty per cent, about twenty per cent by weight being added. (This additional turpentine is added in order that the gum may be light enough to be separated from the water in a later step.) This mass is heated to around two hundred and ten degrees Fahrenheit in order that the charge be completely melted. This melting period varies from thirty minutes to a maximum of one hour. The heating is accomplished by the addition of live steam. The melter

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[10]U.S. Patent 2,254,785 to W.C. Smith, J.O. Reed, F. P. Veitch, and G.P. Shingler, September 2, 1941.

is equipped with a four-mesh basket filter. The main portion of the steam enters through a pipe at the bottom, but an extra coil is provided just above the basket filter for the sparging of additional steam. This extra steam is added to prevent the gum from solidifying on the ledge above the filter and being reheated and subjected to possible decomposition with the effect of darkening the rosin and lowering its grade. When the melting is complete, the pressure on the melted gum is raised to about fifty pounds gauge and the material forced through the screen filter and into the filter proper.

The filters are hollow drum like affairs, approximating the leaf-type in the method of operation. The filtering media consists of one round of filter paper, three rounds of cotton batting, and one round of burlap. The filtering operation usually consumes some twenty minutes. The temperature range is from two hundred and ten to two hundred and thirty degrees Fahrenheit. From the filters the filtrate of turpentine-water-rosin mixture goes to the settling tanks.

In the settling tanks has been placed one-half to one-third as much water as gum, by volume. The water is pre-heated to about one hundred and fifty degrees Fahrenheit. The gum is jetted into the water and thorough mixing occurs. The resultant temperature is from one hundred and eighty to one hundred and ninety degrees Fahrenheit. Due to dilution with turpentine, the gum is lighter than the water and is

allowed to settle and separate from the water layer for a minimum of seven hours and a maximum of around twenty-four. The temperature is maintained within the specified range of temperature by controlling the temperature of the wash water and by means of a steam-water jacket on the tank. Were some precaution not taken, there would be a turpentine loss when the filtrate is jetted into the tanks in the presence of steam--assuming that all of the steam would not be condensed which is likely. To prevent this, each settling tank is equipped with a reflux condenser.

In the meantime, about two hundred and ninety pounds of turpentine, or a third as much as has been added originally, is added to the chips, etc., remaining in the melter in order that the gum may be completely removed and a sizeable saving effected, for otherwise the gum adhering to the chips would be lost. The process is then the same for the extracted gum-turpentine mixture as for the original charge.

After sufficient settling time, the wash-water is drawn off and discarded; the diluted, filtered gum of turpentine content approximating forty per cent is run into a charging tank where the charge is weighed and then pumped into the steam still. An average charge is about three thousand five hundred pounds of gum and turpentine combined.

The entire distillation usually requires about two hours. When the charge is in the still, the steam coils are turned on, and after about fifteen minutes the first

distillate of turpentine-acid mixture comes over. After several minutes of this sort of distillation and when the water content begins to get low, additional steam is sparged in together with water and the distillation is continued to completion. The temperature within the still has steadily risen until the final distillate is sent over at a still temperature of about three hundred and fifteen degrees Fahrenheit, and the per cent of turpentine in the distillate has decreased from a maximum of about eighty to ten per cent. At this point the steam is cut off, and the rosin is removed from the tank and stored for shipment--samples for grading being taken during the emptying process. Temperature control during the distillation period is effected by controlling the amount of water added together with the quantity and temperature of the steam added.

The turpentine is separated from the low wine--the water layer containing acidic impurities together with a little turpentine, by a baffle effect, the turpentine layer flowing over the top and then coming up through a layer of anhydrous salt which dries it. The turpentine is ready for market or reuse in the process.

EQUIPMENT

Metal Samples

The metals tested were the following:

(1) Aluminum 2S, half hard sheet, 2B finish and .032 inches in thickness.

(2) Copper, Anaconda, cold rolled sheet of 2B finish, .032 inches in thickness.

(3) USS Cor-Ten, ten gauge thickness, .135 inches.

(4) Inconel, soft temper, 2B finish and .031 inches inthickness.

(5) Monel, soft temper, 2B finish, .031 inches in thickness.

(6) Nickel, soft temper, 2B finish, .031 inches in thickness.

(7) Copper bearing low carbon steel, hot rolled sheets of .100 inches in thickness.

(8) USS 18-8 stainless steel of high carbon content, Type 302, 2B finish and .037 inches in thickness.

(9) USS 18-8 S of low carbon contect, Type 304, 2B finish and .030 inches in thickness.

(10) USS 18-8 containing molybdenum, Type 316, 2B finish and .0345 inches in thickness.

(11) USS 18-8 containing columbium, Type 347, 2B finish and .033 inches in thickness.

(12) Mild steel sheet of .0404 inches thickness.

Sample Holders

The sample holders in general consisted of strips of wood, eleven and one-half inches by one-half inch by one-fourth inch, bolted at the extreme tops and bottoms with galvanized iron bolts. Glass rods of five millimeters diameter were mounted horizontally in counter-sunk holes. From these rods the samples were suspended.

In the case of the melter, the clearance was so small that the width of the entire holder was limited to one and one-half inches. This necessitated mounting the twelve samples to be tested in groups of six, one group above the other, in the liquid and vapor phases respectively. Only one group could be tested in each phase for a given run.

The sample holder for the washing unit was four and one-half inches wide. Three glass rods, spaced at equal increments along the wooden supports, enabled three sets of samples to be tested--one in each of the three phases.

The sample holder used in the still was identical with that used in the washing tank except that four complete sets of samples could be mounted simultaneously, two in each of the two phases.

Melting Unit

The equipment for the melter consisted of the following: an over-head feed tank of five gallons capacity equipped with a crude filter of screen wire (This filter was included

to remove chips, needles, etc..) and a standard one-half inch cast iron pipe as a feed outlet; a one-half inch globe valve for regulating the feed rate; a feed inlet of fourteen millimeters outside diameter pyrex glass which extended within one-half inch of the bottom; a steam sparger of equal length; an inner container, approximately three inches in diameter, where the melting process proper occurred; an outer container which served to form an air bath; a heating coil for the air bath; a steam generator equipped with a surge tube to enable pressures slightly above atmospheric to be maintained and, at the same time, to act as a safety factor against excessive pressures in case the steam outlet should become clogged; a glass cover-plate; and an outside metal container and metal cover-plate.

The two pyrex containers, shown in Figure 1, Drawings B and C, were assembled as shown in Figure 1, Drawing D, with sheet neoprene rubber between the bottom glass surfaces. Cork stoppers were bored and fitted into the side arms. (This arrangement was included in case an air bath proved unsatisfactory and an oil bath had to be used.) These two units were in turn mounted in a protecting container made of standard eight inch cast iron pipe, slotted as shown in Figures 2, 3, and 4, with a sheet metal bottom welded in place. (These slots enabled the operator to see within each unit at all times.) Around the top of the iron container one-inch angle iron was bent and bolted to provide a surface for

clamping the cover in place. This clamping was accomplished by the use of a sheet metal top, ten inches in diameter, with holes drilled for gum and steam inlets. Cork gaskets were used between the two cover plates and between the cover-plate and the inner container. This minimized the hazard of breakage and provided a vapor-tight seal.

The specifications for the pyrex cover-plate are given in Figure 1, Drawing F, and those for the gum inlet and steam inlet in Figure 1, Drawings I and H, respectively. The ground-glass joints were necessary to prevent the escape of vapors and to facilitate handling and cleaning.

The heating element of ten millimeter pyrex glass was a peculiar one, designed to fit this particular case. It consisted of a series of V-bends; the tops and bottoms of the bends falling on a circle of about four and one-half inches in diameter. This type construction enabled the element to fit over the side-arm assembly. Nichrome resistance wire was pulled through the tube and the completed element connected in series with a six hundred and sixty watt resistance. This gave a temperature of about two hundred and forty degrees Fahrenheit in the outside air bath and the desired temperature of two hundred and twenty degrees Fahrenheit within. The complete unit is shown in Figures 2A and 2B.

Still and Washing Units

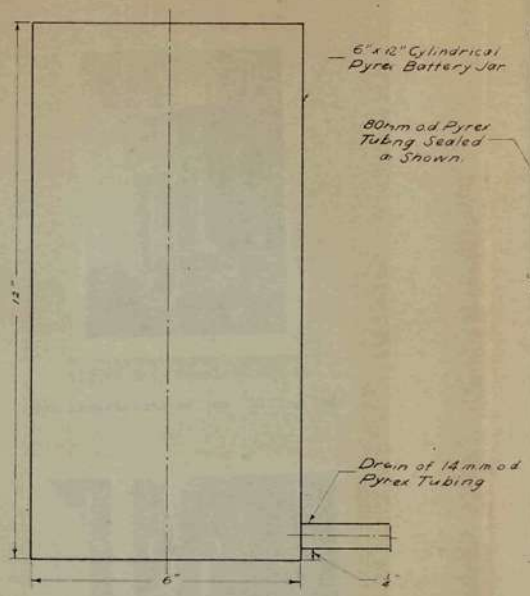
The essential pieces of equipment for the still and the

washing unit were identical. The principal container was fabricated from a cylindrical pyrex battery jar, six inches by twelve inches, as shown in Figure 1, Drawing A; the glass cover, as shown in Drawing E. The outside cast iron container was identical in each case with that described previously for the melter. The metal cover-plate, however, differed in that four holes were drilled to allow for the various inlets and outlets--two steam inlets, vapor outlet, and thermometer opening.

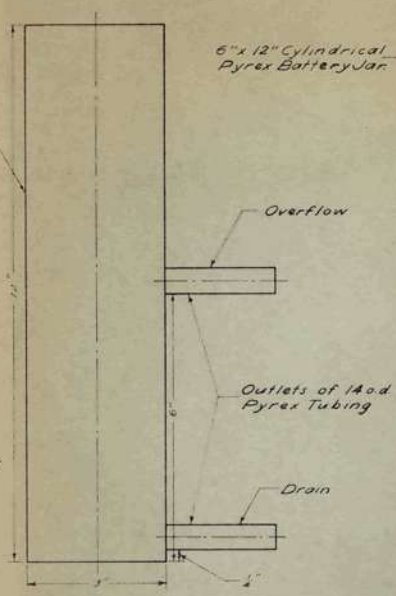
The set-up for the two units differed in the arrangement of the condensers and the thermometers. (Figures 3 and 4.) Whereas in the still the vapors were condensed and collected outside the unit, they were condensed and returned to the liquid within, in the case of the washing unit. The thermometer in the washing tank was introduced through the cover-plate and extended mid-way into the gum phase. In the still the thermometer was introduced through the drain and extended to the center of the container between the two spargers. When a run was completed, the thermometer was pulled out, leaving the drain completely open.

The original design of equipment for the still incorporated the use of a glass steam coil for preliminary heating and secondary temperature control with the steam to the sparger entering the third opening. It was found, however, that the use of this coil increased the recharging time without aiding materially in any way; so it was removed.

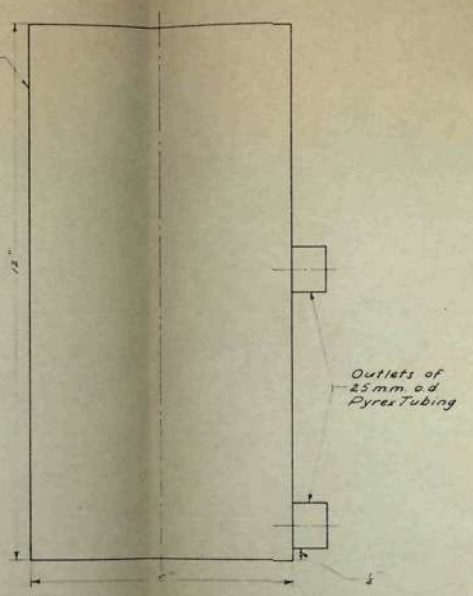
Miscellaneous equipment included screw clamps for holding the covers in place; neoprene tubing of varying diameters for use as connections and, when cut into washers, as insulating material between the metal specimens; a three-way General Electric heater for the steam generator on the melter in order that the unit could be run continuously twenty-four hours each day, and an open-coil heater for the still. These heaters are shown in Figures 2 and 4 respectively.



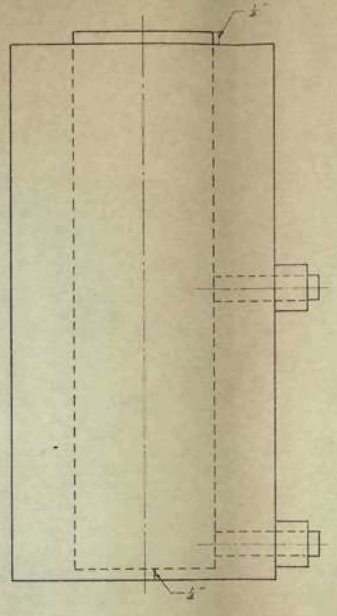
Drawing A



Drawing B



Drawing C



Drawing D
Containers B and C Assembled

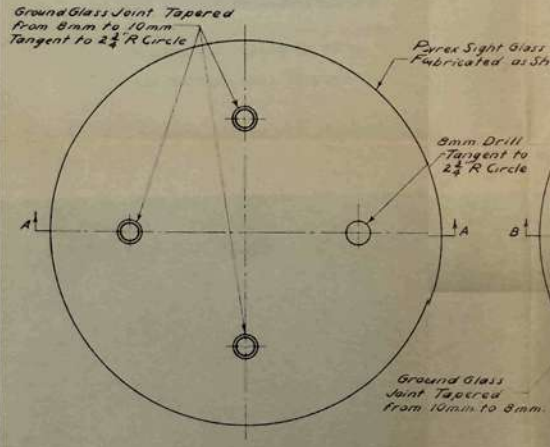


Plate Cover : Top View
Drawing E

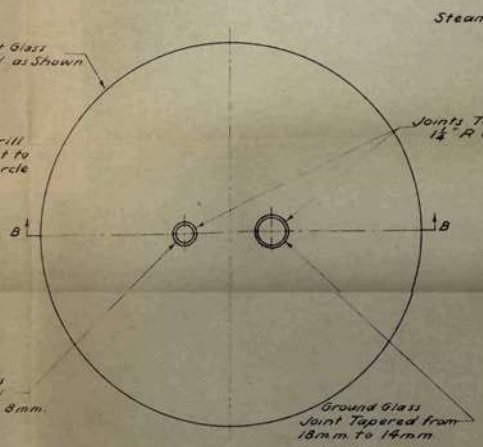
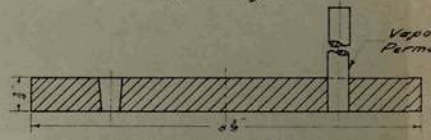
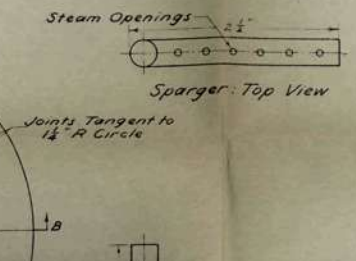


Plate Cover . Top View
Drawing F



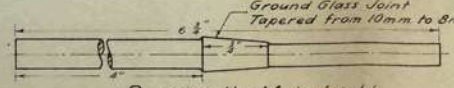
Section A-A of Plate Cover

Section B-B of Plate Cover

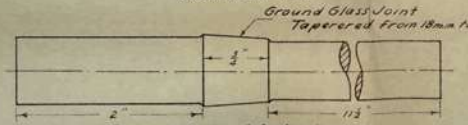


Sparger : Top View

Steam Sparger : Front View
Drawing G
Scale : Full Size



Drawing H : Male Joint 1
Scale : Full Size



Drawing I : Male Joint 2
Scale : Full Size

Bill of Materials		
Container A	Pyrex	2
Container B	Pyrex	1
Container C	Pyrex	1
Cover Plate E	Pyrex	2
Cover Plate F	Pyrex	1
Sparger G	Pyrex	5
Joint H 1	Pyrex	7
Joint I 2	Pyrex	1

Scale : ½" = 1" or as Noted

Figure 1.

Figure 2a: Complete Set-Up
for Experiments of the Melting Unit

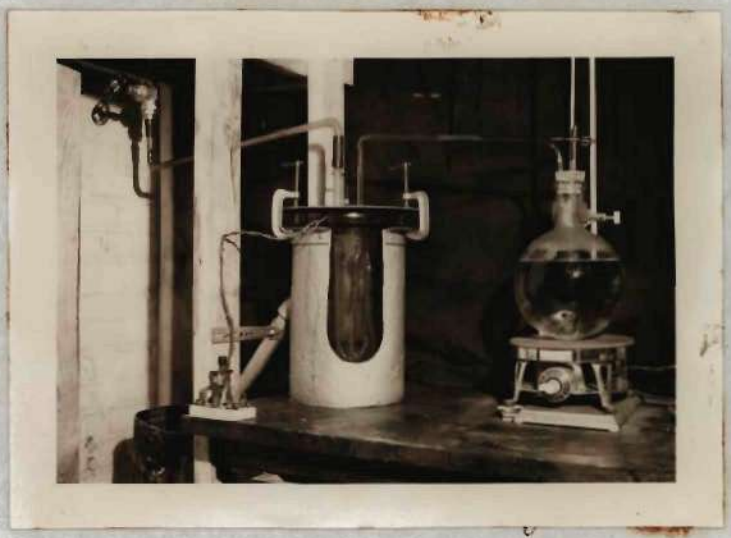


Figure 2b: Close-Up of
the Melting Unit Proper

Figure 3: Complete Set-Up for Experiments on the Washing Unit

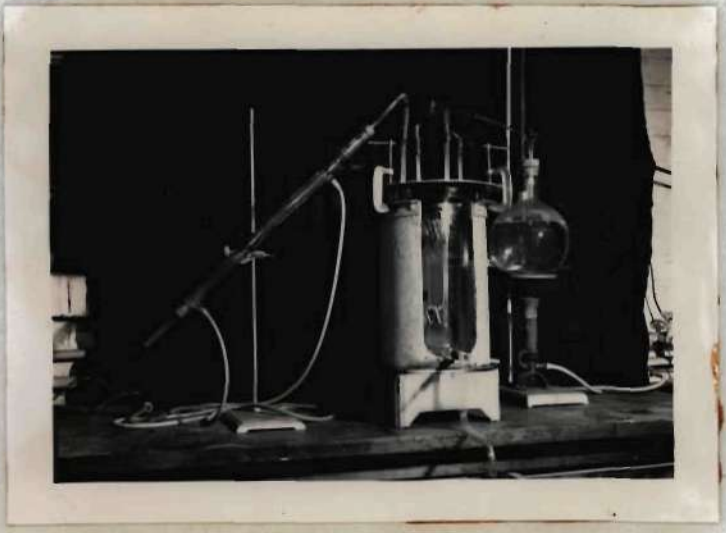


Figure 4: Complete Set-Up
for Experiments on the Still

EXPERIMENTAL PROCEDURE

Preparation of the Samples

Samples used in the corrosion tests were prepared from the different metals and alloys listed in the preceding division. Squares, approximately one and one-half inches on a side, were cut from each type. A hole, thirteen sixty-fourths of one inch in diameter, was drilled in the corner of each of the samples.

Samples which were to be exposed were washed in an alcohol-ether mixture and brushed free of any adhering substances using an ordinary soft-bristled brush. They were rinsed after washing through three more alcohol-ether mixtures and allowed to dry. When dry, the samples were weighed to the nearest tenth of a milligram. The dimensions were measured to the nearest one one-hundredth of an inch.

In preparing for exposure, the metals and alloys were placed on glass rods, separated from one another by washers of neoprene tubing, and then mounted in the sample holder. The holder was placed in the unit on which the test was being made in a vertical position so that the corrosive media would flow uniformly between each sample. After exposure, the samples were cleaned as before and reweighed. The differences in the weights of the samples before and after exposure were indices of corrosion.

To be sure that no pitting had occurred, each of the

specimens from the separate phases of the two-hundred and four and the three hundred and sixty hour runs was mounted in bakelite, a thermo-setting plastic, and subjected to microscopic examination. The mounting was made in cross-section and was compared to a similar mounting of the original sample in each case.

Test specimens were suspended in the melter liquid and in the melter vapor; three test specimens were installed in the washing tank, one in the diluted gum, one in the wash-water layer, and one in the vapor phase. Two sample groups were mounted in the still, one in the vapor phase and one in the still liquid.

The periods of exposure included twelve hours, twenty-four hours, forty-eight hours, ninety hours, one hundred and forty-four hours, two hundred and four hours, and three hundred and sixty hours. The first four periods were run in duplicate and the results averaged to give the corrosion rate.

The Melting Unit

In the melting unit or "melter", as in each of the other units, the procedure duplicated as closely as possible the conditions encountered in the industrial cleaning plant. The operation of the unit was a continuous one inaugurated to cut charging time to a minimum.

The crude gum from the pine trees, oleoresin, was diluted to about forty per cent turpentine content. The dilution was made on the basis of an original turpentine content

of twenty per cent. This step was necessary to reduce the viscosity of the gum in order that it might be fed continuously into the unit without resorting to increased temperatures and pressures. The oleoresin was poured into an overhead tank; the chips, needles, etc., removed by means of a coarse filter of screen wire. The flow rate was regulated by a globe valve. Steam was generated and introduced into the unit through the steam sparger. The uniformity of the steam introduction was maintained by a constant heat supply to the generator. Issuing steam served to agitate the water-gum-turpentine mixture.

The temperature of the unit was maintained at two hundred and twenty degrees Fahrenheit by means of a heating coil in the air bath surrounding the inner container.

The raw gum entered the bottom of the unit, flowed upward past the samples and out the overflow. The period of detention, dependent on the rate of flow, was regulated to about three hours. Time was recorded when the samples were introduced and when they were removed.

Washing Tank

The gum-turpentine sample for the washing operation had been melted and filtered. The washing of one particular charge covered a period of twelve hours at a temperature of one hundred and eighty to one hundred and ninety degrees Fahrenheit.

The container was filled one-third full of fresh water, preheated to the temperature mentioned above. The volume of water amounted to about three pints. An equal volume of sample gum was introduced and steam sparged in. The rate of steam introduction was governed in a small measure by the temperature of the surroundings and was sufficient to maintain the desired temperature in the unit.

As the temperature increased, the turpentine-gum mixture became emulsified by the upward passage and partial condensation of the steam. The uncondensed steam vapors, together with volatile materials present in the charge, passed out of the unit, were condensed and returned. The downward flow of water gave the desired washing.

The original volume was maintained by a constant-level drain as shown in Figure 3.

When the washing operation had been completed, the steam was vented to the air, the unit drained, a new charge introduced, and the process begun anew. The twelve hour interval covered the period from initial to final steam introduction.

Still

The turpentine-gum sample for corrosion studies in the still had been melted, filtered, and washed. A steam distillation was run.

In beginning a run, the unit was dismantled; the drain

closed, and the container charged to the half-way mark. The electric heater was plugged in, and the unit closed. When the temperature reached one hundred degrees Fahrenheit, steam introduction was begun, and the time recorded. Since the final temperature desired at the end of the distillation was between three hundred and ten and three hundred and fifteen degrees Fahrenheit, and since the distillation time was set for four hours, the temperature rise was set as follows: During the first hour the temperature rise was from one hundred degrees Fahrenheit to two hundred and twenty degrees Fahrenheit; during the second hour, from two hundred and twenty to two hundred and fifty; from two hundred and fifty to two hundred and eighty during the third hour; and from two hundred and eighty to three hundred and ten degrees Fahrenheit for the fourth hour.

Temperature control was difficult. It depended on the rate of heat generation by the heater and the rate of steam supply. The rise was held in the specified limits by manual control of these two factors. Toward the latter part of the distillation--during the last hour, steam was introduced at an accelerated rate in order that residual volatile products be completely removed.

The vapors passed through the outlet and were condensed. This condensate separated into two layers--the turpentine layer and a water solution of turpentine plus water solubles termed "low wines". The two layers were separated by

decantation and the turpentine used in the dilution of the crude gum for the melting unit.

After the distillation was complete, the steam generator was vented, the heater turned off, and the residue, rosin, drained out. After cooling slightly, the unit was recharged and the procedure repeated. The process was accelerated after the initial run due to the fact that residual heat in the container was sufficient to bring the temperature of the gum to one hundred degrees Fahrenheit, the starting point of the succeeding distillation.

EXPERIMENTAL DATA AND RESULTS

Table IA
Melter; Liquid Phase Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.624	.0003	0.650	9.84
Copper	4.624	.0022	4.760	22.67
Cor-Ten	5.544	.1287	236.7	1108.
Inconel	4.256	.0000	0.0	0.0
Monel	4.534	.0007	1.544	7.25
Nickel	4.396	.0007	1.592	7.50
Copper Steel	5.838	.0822	141.0	764.
Mild Steel	4.220	.0629	149.1	781.
Steel 302	4.496	.0001	.223	1.17
Steel 302	4.344	-.0001	-.240	-1.33
Steel 316	4.584	.0000	0.0	0.0
Steel 347	3.986	.0000	0.0	0.0

Table IB
Melter: Liquid Phase Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.466	.0004	.896	6.55
Copper	4.568	.0018	3.94	9.375
Cor-Ten	5.404	.1802	335.6	903.
Inconel	4.306	.0004	.920	2.26
Monel	4.136	.0004	.968	2.27
Nickel	3.870	.0004	1.032	2.425
Copper Steel	5.314	.0778	145.1	393.
Mild Steel	4.426	.1482	335.	888.
Steel 302	4.316	.0000	0.0	0.0
Steel 304	4.424	-.0001	-.226	-.589
Steel 316	4.484	.0002	.446	1.157
Steel 347	4.320	.0003	.694	1.798

Table IC

Melter: Liquid Phase Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.624	.0005	1.037	3.92
Copper	4.792	.0016	3.405	4.05
Cor-Ten	5.750	.0844	429.	578.
Inconel	4.306	.0003	.697	.807
Monel	4.404	.0010	2.27	2.665
Nickel	4.456	.0006	1.345	1.58
Copper Steel	5.570	.1307	234.7	318.
Mild Steel	4.426	.0169	38.9	51.3
Steel 302	4.466	.0000	0.0	0.0
Steel 304	4.302	.0000	0.0	0.0
Steel 316	4.420	.0001	.2265	.294
Steel 347	4.108	.0001	.234	.303

Table ID

Melter: Liquid Phase Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.312	.0010	2.32	4.38
Copper	4.822	.0024	4.98	2.96
Cor-Ten	5.690	.1675	294.5	198.3
Inconel	4.280	.0003	.700	.430
Monel	4.228	.0010	2.37	1.39
Nickel	3.962	.0011	2.775	1.63
Copper Steel	5.704	.0275	48.0	32.5
Mild Steel	4.342	.0197	45.4	30.1
Steel 302	4.598	-.0001	-.218	-.1434
Steel 304	4.274	.0000	0.0	0.0
Steel 316	4.328	.0001	.231	.150
Steel 347	4.206	.0002	.476	.308

Table IE

Melter: Liquid Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.374	.0017	3.882	4.92
Copper	4.536	.0030	6.61	2.62
Cor-Ten	5.594	.2558	457.	204.5
Inconel	4.460	.0001	.224	.092
Monel	4.198	.0006	1.431	.561
Nickel	4.528	.0019	4.18	1.64
Copper Steel	5.742	.0386	67.2	30.4
Mild Steel	4.312	.0268	62.2	27.47
Steel 302	4.630	.0000	0.0	0.0
Steel 304	4.556	.0000	0.0	0.0
Steel 316	4.450	.0000	0.0	0.0
Steel 347	4.236	.0003	.707	.305

Table IF

Melter: Liquid Phase

Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.286	.0004	.934	.829
Copper	4.864	.0033	6.29	1.896
Cor-Ten	5.852	.4818	823.	260.0
Inconel	4.348	.0001	.230	.0666
Monel	4.258	.0016	3.76	1.04
Nickel	4.222	.0019	4.5	1.244
Copper Steel	5.912	.0721	122.	38.83
Mild Steel	4.364	.0460	105.3	32.85
Steel 302	4.340	.0000	0.0	0.0
Steel 304	4.240	.0001	.226	.0693
Steel 316	4.482	-.0002	-.446	-.136
Steel 347	4.298	.0002	.446	.1418

Table IG

Melter: Liquid Phase
Three Hundred and Sixty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.464	.0009	2.014	1.014
Copper	4.598	.0026	5.66	.8975
Cor-Ten	5.512	.9368	1700.	305.7
Inconel	4.348	-.0001	-.230	-.0377
Monel	4.282	.0017	3.965	.621
Nickel	4.344	.0032	7.375	1.153
Copper Steel	5.700	.2835	497.	89.76
Mild Steel	4.250	.1366	321.5	56.8
Steel 302	4.496	.0000	0.0	0.0
Steel 304	4.392	.0000	0.0	0.0
Steel 316	4.524	.0000	0.0	0.0
Steel 347	4.376	.0009	2.55	.390

Table IIA

Melter: Liquid Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.294	.0002	.466	7.04
Copper	4.824	.0017	3.525	16.78
Cor-Ten	5.854	.0301	51.4	277.
Inconel	4.224	.0001	.2367	1.163
Monel	4.288	.0005	1.163	5.475
Nickel	4.588	.0008	1.741	8.18
Copper Steel	5.594	.0038	6.795	36.8
Mild Steel	4.424	.0021	4.75	25.2
Steel 302	4.466	-.0001	-.224	-1.18
Steel 304	4.250	.0000	0.0	0.0
Steel 316	4.524	.0000	0.0	0.0
Steel 347	4.318	.0000	0.0	0.0

Table II B

Melter: Vapor Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.312	.0003	.695	5.25
Copper	4.944	.0030	6.08	14.47
Cor-Ten	5.686	.0449	79.0	212.5
Inconel	4.592	.0005	1.1112	2.74
Monel	4.288	.0013	3.03	7.12
Nickel	3.868	.0022	5.69	13.34
Copper Steel	5.604	.0053	9.46	25.6
Mild Steel	4.486	.0038	8.47	22.45
Steel 302	4.496	.0000	0.0	0.0
Steel 304	4.218	-.0001	-.237	-.618
Steel 316	4.552	-.0002	-.440	-1.143
Steel 347	4.176	.0000	0.0	0.0

Table II C

Melter: Vapor Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss Per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.508	.0003	.665	2.515
Copper	4.598	.0044	9.58	11.39
Cor-Ten	5.676	.0666	117.4	158.0
Inconel	4.346	.0000	0.0	0.0
Monel	4.402	.0012	2.73	3.21
Nickel	4.854	.0012	2.475	2.91
Copper Steel	5.870	.0189	32.2	43.6
Mild Steel	4.456	.0078	17.5	23.2
Steel 302	4.646	.0000	0.0	0.0
Steel 304	4.342	.0000	0.0	0.0
Steel 316	4.552	.0000	0.0	0.0
Steel 347	4.410	.0001	.293	.302

Table II D

Melter: Vapor Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.260	.0005	2.04	2.04
Copper	4.924	.0055	11.17	6.65
Cor-Ten	5.644	.0357	63.3	42.6
Inconel	4.398	.0000	0.0	0.0
Monel	4.372	.0018	4.12	2.42
Nickel	4.426	.0028	6.325	3.715
Copper Steel	5.870	.0035	5.96	4.03
Mild Steel	4.424	.0045	10.18	6.75
Steel 302	4.322	.0000	0.0	0.0
Steel 304	4.340	.0000	0.0	0.0
Steel 316	4.388	.0001	.2276	.148
Steel 347	4.206	-.0001	-.238	-.1538

Table II E

Melter: Vapor Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.300	.0001	.2122	.268
Copper	4.634	.0053	11.54	4.54
Cor-Ten	5.712	.0439	76.9	34.5
Inconel	4.286	.0002	.466	.185
Monel	4.432	.0013	2.935	1.15
Nickel	4.528	.0030	6.625	2.595
Copper Steel	5.806	.0065	11.20	5.05
Mild Steel	4.486	.0029	6.46	2.86
Steel 302	4.414	-.0003	.68	.2985
Steel 304	4.158	.0000	0.0	0.0
Steel 316	4.524	.0003	.6625	.287
Steel 347	4.266	.0000	0.0	0.0

Table II F

Melter: Vapor Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.700	.0001	.2172	.189
Copper	4.570	.0103	22.52	6.31
Cor-Ten	5.610	.0742	132.2	41.8
Inconel	4.280	.0001	.233	.0675
Monel	4.534	.0012	2.65	.732
Nickel	4.588	.0046	10.02	2.75
Copper Steel	5.986	.0123	20.55	6.55
Mild Steel	4.520	.0071	15.7	4.90
Steel 302	4.518	.0000	0.0	0.0
Steel 304	4.280	.0001	.233	.07225
Steel 316	4.552	.0000	0.0	0.0
Steel 347	4.176	-.0001	-.239	-.0729

Table II G

Melter: Vapor Phase
Three Hundred and Sixty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.660	.0004	.858	.432
Copper	4.730	.0191	40.3	6.41
Cor-Ten	6.108	.2099	343.7	61.7
Inconel	4.530	.0002	.432	.0726
Monel	4.288	.0043	10.02	1.57
Nickel	4.588	.0077	16.80	2.625
Copper Steel	5.678	.0226	39.8	7.19
Mild Steel	4.424	.0189	42.7	7.56
Steel 302	4.662	-.0001	-.2143	-.0376
Steel 304	4.392	.0000	0.0	00
Steel 316	4.482	-.0001	-.225	-.0386
Steel 347	4.236	.0001	.236	.0407

Table III A

Still: Liquid Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.434	.0013	2.93	44.3
Copper	4.700	.0029	6.17	29.4
Cor-Ten	5.890	.0673	114.2	616.
Inconel	4.164	.0001	.24	1.18
Monel	4.462	.0010	2.24	10.52
Nickel	4.304	.0012	2.79	13.1
Copper Steel	5.494	.0330	58.0	314.
Mild Steel	4.456	.0247	55.4	294.
Steel 302	4.340	.0000	0.0	0.0
Steel 304	4.300	.0001	.2325	1.223
Steel 316	4.450	-.0001	-.2247	-1.168
Steel 347	4.380	.0002	.457	2.362

Table III B

Still: Liquid Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.792	.0017	3.55	26.8
Copper	4.700	.0042	8.94	21.3
Cor-Ten	5.686	.0784	138.0	371.5
Inconel	4.428	.0000	0.0	0.0
Monel	4.462	.0017	3.803	8.93
Nickel	4.344	.0022	5.07	11.90
Copper Steel	5.906	.0401	68.0	184.0
Mild Steel	4.362	.0251	57.5	152.5
Steel 302	4.434	.0000	0.0	0.0
Steel 304	4.646	.0000	0.0	0.0
Steel 316	4.388	-.0001	-.228	-.592
Steel 347	4.144	.0001	.2415	.625

Table III C

Still: Liquid Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.762	.0022	4.62	17.45
Copper	4.822	.0072	14.93	16.4
Cor-Ten	5.576	.1181	212.	286.
Inconel	4.040	.0000	0.0	0.0
Monel	4.310	.0029	6.73	7.30
Nickel	4.394	.0060	13.66	14.8
Copper Steel	5.980	.0700	117.0	146.1
Mild Steel	4.362	.0420	96.3	127.9
Steel 302	4.268	.0000	0.0	0.0
Steel 304	4.422	-.0001	-.225	-.290
Steel 316	4.500	.0002	.445	.5775
Steel 347	4.318	.0002	.457	.831

Table III D

Still: Liquid Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.434	.0031	7.00	12.93
Copper	4.630	.0106	22.9	13.08
Cor-Ten	5.852	.1947	332.5	219.5
Inconel	4.286	.0000	0.0	0.0
Monel	4.282	.0064	14.91	8.60
Nickel	4.573	.0099	22.8	13.00
Copper Steel	5.638	.0591	105.0	66.9
Mild Steel	4.444	.0459	103.0	65.5
Steel 302	4.762	.0002	.420	.265
Steel 304	4.583	.0000	0.0	0.0
Steel 316	4.420	.0004	.905	.576
Steel 347	4.228	.0004	.938	.580

Table III E

Still: Liquid Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.598	.0127	27.7	34.3
Copper	4.862	.0196	40.25	15.79
Cor-Ten	5.820	.3379	580.	257.
Inconel	4.530	-.0001	-.2203	-.0902
Monel	4.308	.0120	27.9	10.76
Nickel	4.528	.0168	37.1	14.32
Copper Steel	5.842	.1193	204.5	91.0
Mild Steel	4.486	.0928	207.	90.1
Steel 302	4.792	.0003	.626	.271
Steel 304	4.300	.0002	.465	.199
Steel 316	4.456	-.0001	-.2243	-.0958
Steel 347	4.144	.0004	.965	.411

Table III F

Still: Liquid Phase
One Hundred and Seventy-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.660	.0064	13.71	14.14
Copper	4.630	.0197	42.6	13.8
Cor-Ten	5.852	.2437	416.	152.9
Inconel	4.254	.0000	0.0	0.0
Monel	4.196	.0128	30.5	9.78
Nickel	4.500	.0235	52.25	16.75
Copper Steel	5.990	.2767	462.5	170.9
Mild Steel	4.424	.0910	205.5	74.3
Steel 302	4.568	.0000	0.0	0.0
Steel 304	4.340	.0000	0.0	0.0
Steel 316	4.450	.0001	.228	.0795
Steel 347	4.298	.0004	.931	.329

Table III G

Still: Liquid Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.574	.0040	8.75	7.76
Copper	4.894	.0240	49.0	13.7
Cor-Ten	6.236	.2506	402.	127.5
Inconel	4.398	.0000	0.0	0.0
Monel	4.492	.0175	39.0	10.77
Nickel	4.426	.0295	66.6	18.4
Copper Steel	4.976	.1453	293.	93.8
Mild Steel	4.516	.1224	271.	84.6
Steel 302	4.538	.0000	0.0	0.0
Steel 304	4.280	.0000	0.0	0.0
Steel 316	4.306	.0004	.929	.284
Steel 347	4.236	.0008	1.89	.575

Table III H

Still: Liquid Phase
Three Hundred and Thirty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.466	.0041	9.175	5.05
Copper	4.660	.0315	67.5	16.9
Cor-Ten	5.712	.3801	665.	130.5
Inconel	4.346	.0002	.461	.0874
Monel	4.166	.0257	61.7	10.55
Nickel	4.344	.0362	83.5	14.28
Copper Steel	5.768	.3594	623.	122.5
Mild Steel	4.362	.2738	607.5	121.
Steel 302	4.496	.0001	.223	.0426
Steel 304	4.220	-.0001	- .237	-.045
Steel 316	4.524	.0002	.442	.0761
Steel 347	4.236	.0002	.472	.0816

Table IV A

Still: Vapor Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.598	.0004	.871	13.10
Copper	4.760	.0026	5.46	26.0
Cor-Ten	5.890	.0298	50.6	273.
Inconel	4.346	.0001	.23	1.131
Monel	4.288	.0005	1.167	5.48
Nickel	3.786	.0005	1.582	7.45
Copper Steel	6.018	.0104	17.3	93.6
Mild Steel	4.312	.0099	22.95	121.8
Steel 302	4.538	-.0001	-.220	-1.160
Steel 304	4.220	.0000	0.0	0.0
Steel 316	4.392	.0001	.228	1.185
Steel 347	4.236	.0002	.4725	2.445

Table IV B

Still: Vapor Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.494	.0006	1.337	10.10
Copper	4.792	.0039	8.15	19.40
Cor-Ten	5.544	.0453	82.0	220.7
Inconel	4.368	.0001	.229	.5625
Monel	4.370	.0019	4.35	10.21
Nickel	4.426	.0026	5.875	13.80
Copper Steel	5.662	.0303	53.5	145.0
Mild Steel	4.168	.0155	37.2	98.5
Steel 302	4.340	.0001	.2305	.607
Steel 304	4.280	.0000	0.0	0.0
Steel 316	4.420	.0001	.226	.5875
Steel 347	4.378	.0004	.915	2.368

Table IV C

Still: Vapor Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.864	.0010	2.055	7.76
Copper	4.598	.0047	10.22	11.24
Cor-Ten	5.870	.0722	122.0	165.3
Inconel	4.306	.0002	.465	.527
Monel	4.104	.0028	6.82	7.39
Nickel	4.498	.0058	12.90	14.00
Copper Steel	5.662	.0420	74.7	93.4
Mild Steel	4.312	.0293	69.0	82.6
Steel 302	4.568	.0002	.4375	.532
Steel 304	4.280	.0001	.2335	.2805
Steel 316	4.480	.0000	0.0	0.0
Steel 347	4.380	.0006	1.37	1.638

Table IV D

Still: Vapor Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.568	.0013	2.845	5.16
Copper	4.791	.0100	20,80	12.12
Cor-Ten	5.716	.0779	136.2	88.0
Inconel	4.460	.0000	0.0	0.0
Monel	4.462	.0065	14.56	8.2
Nickel	4.486	.0115	25.6	14.43
Copper Steel	5.870	.0498	85.0	57.5
Mild Steel	4.362	.0377	86.5	55.0
Steel 302	4.290	.0001	2.33	.1472
Steel 304	4.392	.0000	0.0	0.0
Steel 316	4.420	.0003	.68	.441
Steel 347	4.472	.0006	1.341	.836

Table IV E

Still: Vapor Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.374	.0014	3.2	3.975
Copper	4.926	.0139	28.2	11.05
Cor-Ten	6.476	.1878	290.	184.0
Inconel	4.260	.0001	.235	.0949
Monel	4.310	.0089	20.67	7.97
Nickel	4.528	.0146	32.25	12.45
Copper Steel	5.870	.0659	112.2	50.0
Mild Steel	4.280	.0651	152.0	66.2
Steel 302	4.568	.0002	.4375	.1891
Steel 304	4.250	.0000	0.0	0.0
Steel 316	4.388	.0002	.456	.1949
Steel 347	4.236	.0006	1.418	.6025

Table IV F

Still: Vapor Phase
One Hundred and Seventy-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.568	.0007	1.500	1.545
Copper	4.598	.0167	36.38	11.8
Cor-Ten	5.584	.0707	126.8	46.55
Inconel	4.040	.0000	0.0	0.0
Monel	4.136	.0089	21.55	6.90
Nickel	4.498	.0239	53.2	17.04
Copper Steel	6.194	.0836	135.1	49.9
Mild Steel	4.454	.0794	178.1	64.5
Steel 302	4.628	.0000	0.0	0.0
Steel 304	4.098	.0002	.489	.1735
Steel 316	4.450	.0002	.449	.1591
Steel 347	4.144	.0002	.4825	.1703

Table IV G

Still: Vapor Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.730	.0011	2.324	2.065
Copper	4.730	.0198	41.8	11.71
Cor-Ten	5.852	.0785	133.1	42.5
Inconel	4.306	.0000	0.0	0.0
Monel	4.308	.0142	32.95	9.53
Nickel	4.426	.0286	64.6	17.87
Copper Steel	5.680	.2264	398.3	127.0
Mild Steel	4.384	.0851	194.2	60.55
Steel 302	4.464	.0000	..0	0.0
Steel 304	4.188	.0001	.239	.0718
Steel 316	4.524	.0003	.653	.2025
Steel 347	4.206	.0006	1.428	.435

Table IV H

Still: Vapor Phase
Three Hundred and Thirty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.822	.0013	2.597	1.482
Copper	4.792	.0233	48.7	8.44
Cor-Ten	5.712	.1036	181.1	35.5
Inconel	4.102	.0004	.975	.1723
Monel	4.288	.0162	38.8	6.45
Nickel	4.564	.0370	81.0	13.84
Copper Steel	5.662	.1547	273.0	53.75
Mild Steel	4.362	.1008	231.0	44.5
Steel 302	4.538	.0002	.4415	.0845
Steel 304	4.456	.0000	0.0	0.0
Steel 316	4.522	.0004	.885	.1671
Steel 347	4.236	.0006	1.419	.267

Table V A

Washing Tank: Water Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.398	.0001	.2275	3.44
Copper	4.70	.0007	1.490	7.09
Cor-Ten	5.786	.0286	49.5	266.5
Inconel	4.150	-.0001	-.241	-1.183
Monel	4.432	.0008	1.804	8.49
Nickel	4.426	.0004	.905	4.25
Copper Steel	5.954	.0159	26.7	144.5
Mild Steel	4.516	.0094	20.8	110.2
Steel 302	4.496	.0001	.2225	1.171
Steel 304	4.586	.0000	0.0	0.0
Steel 316	4.552	.0000	0.0	0.0
Steel 347	4.298	.0002	.466	2.41

Table V B

Washing Tank: Water Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.404	.0002	.454	3.425
Copper	4.760	.0017	3.57	8.49
Cor-Ten	6.024	.0435	72.2	194.4
Inconel	4.346	.0001	.23	.565
Monel	4.258	.0007	1.642	3.86
Nickel	4.344	.0004	.922	2.62
Copper Steel	5.958	.0261	43.8	118.6
Mild Steel	4.250	.1108	25.4	67.3
Steel 302	4.496	.0000	0,0	0.0
Steel 304	4.352	.0001	.230	.599
Steel 316	4.480	.0000	0.0	0.0
Steel 347	4.358	.0006	1.375	3.56

Table V C

Washing Tank: Water Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.637	.0004	.973	3.61
Copper	4.725	.0042	8.56	10.04
Cor-Ten	5.928	.0777	120.0	158.3
Inconel	4.224	.0000	0.0	0.0
Monel	4.166	.0026	6.24	7.3
Nickel	4.476	.0014	3.1	3.51
Copper Steel	5.924	.0265	44.7	60.6
Mild Steel	4.364	.0224	51.25	66.6
Steel 302	4.496	.0001	.2225	.290
Steel 304	4.362	.0001	.229	.2985
Steel 316	4.276	.0002	.449	.584
Steel 347	4.238	.0001	.236	.3055

Table V D

Washing Tank: Water Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.466	.0008	1.79	3.459
Copper	4.583	.0067	14.4	8.50
Cor-Ten	5.512	.0732	132.9	91.3
Inconel	4.346	.0000	0.0	0.0
Monel	4.264	.0042	9.85	5.5
Nickel	4.350	.0042	9.61	5.528
Copper Steel	5.690	.0659	115.7	80.0
Mild Steel	4.486	.0447	99.5	62.75
Steel 302	4.404	.0000	0.0	0.0
Steel 304	4.392	.0000	0.0	0.0
Steel 316	4.480	.0000	0.0	0.0
Steel 347	4.266	.0000	0.0	0.0

Table V E

Washing Tank: Water Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.464	.0012	2.69	3.295
Copper	4.700	.0101	21.5	8.29
Cor-Ten	6.098	.1575	258.5	113.
Inconel	4.368	-.0002	-.4575	-.1824
Monel	4.264	.0064	14.98	5.71
Nickel	4.252	.0057	13.40	5.10
Copper Steel	6.082	.0994	163.4	71.75
Mild Steel	4.402	.1064	241.7	138.0
Steel 302	4.592	-.0001	-.218	-.093
Steel 304	4.560	.0000	0.0	0.0
Steel 316	4.674	.0001	.214	.0902
Steel 347	4.358	.0001	.229	.0962

Table V F

Washing Tank: Water Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.434	.0012	2.798	2.405
Copper	4.682	.0119	25.4	6.59
Cor-Ten	5.818	.1546	265.6	84.5
Inconel	4.530	.0000	0.0	0.0
Monel	4.258	.0108	23.8	6.575
Nickel	4.358	.0098	22.45	6.21
Copper Steel	5.126	.1011	194.9	62.1
Mild Steel	4.486	.0866	193.0	60.25
Steel 302	4.496	.0000	0.0	0.0
Steel 304	4.340	-.0003	-.692	-.212
Steel 316	4.480	.0003	.669	.2045
Steel 347	4.410	.0003	.680	.2070

Table V G

Washing Tank: Water Phase
Three Hundred and Sixty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.466	.0023	5.15	2.597
Copper	4.760	.0221	46.5	7.37
Cor-Ten	5.578	.2717	487.	87.45
Inconel	4.346	.0000	0.0	0.0
Monel	4.288	.0163	38.0	5.947
Nickel	4.620	.0166	35.94	5.625
Copper Steel	6.090	.1910	314.0	56.7
Mild Steel	4.342	.1710	394.0	69.6
Steel 302	4.538	.0001	.2205	.0387
Steel 304	4.156	-.0001	-.2405	-.0418
Steel 316	4.480	.0002	.446	.07728
Steel 347	4.318	.0002	.463	.0800

Table VI A

Washing Tank: Gum Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.374	.0009	2.057	31.1
Copper	4.792	.0019	3.96	18.89
Cor-Ten	5.684	.0535	94.1	507.
Inconel	4.224	-.0001	-.2367	-1.164
Monel	4.136	.0003	.726	3.41
Nickel	4.344	.0004	.921	4.325
Copper Steel	5.694	.0197	34.6	187.5
Mild Steel	4.454	.0169	37.92	200.9
Steel 302	4.538	.0002	.4415	2.327
Steel 304	4.452	.0001	.2245	1.170
Steel 316	4.614	.0000	0.0	0.0
Steel 347	4.318	.0001	.2313	1.199

Table VI B

Washing Tank: Gum Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.352	.0011	2.525	19.09
Copper	4.424	.0032	7.22	17.20
Cor-Ten	5.818	.0633	108.9	293.
Inconel	4.224	.0002	.473	1.167
Monel	4.290	.0011	2.565	6.025
Nickel	4.588	.0011	2.40	5.64
Copper Steel	5.870	.0335	57.1	154.5
Mild Steel	4.344	.0177	40.75	108.2
Steel 302	4.570	.0000	0.0	0.0
Steel 304	4.190	.0000	0.0	0.0
Steel 316	4.392	.0000	0.0	0.0
Steel 347	4.202	.0002	.476	1.22

Table VI C

Washing Tank: Gum Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.434	.0008	1.803	6.68
Copper	4.568	.0061	13.37	15.59
Cor-Ten	5.264	.0731	138.9	187.0
Inconel	4.102	.0000	0.0	0.0
Monel	4.259	.0021	4.80	5.52
Nickel	4.526	.0039	8.62	9.925
Copper Steel	6.514	.0613	94.1	127.4
Mild Steel	4.404	.0340	77.2	102.3
Steel 302	4.496	.0000	0.0	0.0
Steel 304	4.218	-.0003	-.6975	-.9075
Steel 316	4.522	.0003	.663	.862
Steel 347	4.236	.0000	0.0	0.0

Table VI D

Washing Tank: Gum Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.730	.0024	5.07	9.78
Copper	4.882	.0117	23.95	13.56
Cor-Ten	5.434	.1085	200.0	128.0
Inconel	4.396	.0000	0.0	0.0
Monel	4.432	.0042	9.38	5.78
Nickel	4.394	.0072	16.4	9.85
Copper Steel	5.728	.0823	144.8	100.1
Mild Steel	4.342	.0600	138.3	87.2
Steel 302	4.568	-.0002	-.4375	-.274
Steel 304	4.280	-.0001	-.226	-.140
Steel 316	4.450	.0002	.450	.278
Steel 347	4.318	.0003	.695	.4275

Table VI E

Washing Tank: Gum Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.404	.0029	6.58	8.30
Copper	4.792	.0139	29.0	11.51
Cor-Ten	5.746	.2780	485.0	217.5
Inconel	4.397	.0002	.455	.1861
Monel	4.226	.0065	15.39	6.02
Nickel	4.394	.0073	16.60	6.505
Copper Steel	5.796	.1493	258.	116.3
Mild Steel	4.404	.1203	273.	120.7
Steel 302	4.598	.0001	.2175	.0954
Steel 304	4.340	.0000	0.0	0.0
Steel 316	4.420	.0000	0.0	0.0
Steel 347	4.266	.0000	0.0	0.0

Table VI F

Washing Tank: Gum Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.630	.0034	7.33	6.52
Copper	4.792	.0174	36.3	10.16
Cor-Ten	5.850	.2174	372.	117.9
Inconel	4.398	.0000	0.0	0.0
Monel	4.350	.0102	23.45	6.475
Nickel	4.588	.0119	25.95	7.17
Copper Steel	5.804	.1202	207.3	66.1
Mild Steel	4.424	.0932	210.5	65.8
Steel 302	4.628	.0001	.216	.0670
Steel 304	4.524	.0000	0.0	0.0
Steel 316	4.332	.0001	.2307	.0705
Steel 347	4.410	.0002	.453	.1381

Table VI G

Washing Tank: Gum Phase
Three Hundred and Sixty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.658	.0036	7.73	3.90
Copper	4.792	.0277	57.8	9.18
Cor-Ten	5.641	.3791	672.	120.8
Inconel	4.102	.0000	0.0	0.0
Monel	4.258	.0184	43.1	7.07
Nickel	4.388	.0251	57.25	8.96
Copper Steel	5.874	.2254	383.5	69.2
Mild Steel	4.342	.1877	432.5	76.5
Steel 302	4.524	-.0002	-.4425	-.0767
Steel 304	4.392	.0000	0.0	0.0
Steel 316	4.418	.0000	0.0	0.0
Steel 347	4.266	.0000	.469	.081

Table VII A

Washing Tank: Vapor Phase
Twelve Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.292	.0007	1.631	24.7
Copper	4.598	.0037	8.05	38.3
Cor-Ten	5.684	.0391	68.8	371.
Inconel	4.102	.0001	.244	1.20
Monel	4.432	.0016	3.51	16.95
Nickel	4.252	.0025	5.878	27.6
Copper Steel	5.870	.0350	59.6	323.
Mild Steel	4.362	.0177	40.5	214.9
Steel 302	4.466	.0000	0.0	0.0
Steel 304	4.156	.0000	0.0	0.0
Steel 316	4.528	.0000	0.0	0.0
Steel 347	4.266	.0003	.7025	3.64

Table VII B

Washing Tank: Vapor Phase
Twenty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.462	.0008	1.79	13.53
Copper	4.630	.0044	9.50	22.62
Cor-Ten	5.544	.0565	102.0	274.8
Inconel	4.346	.0001	.2302	.566
Monel	4.462	.0025	5.60	13.14
Nickel	3.798	.0044	10.27	24.15
Copper Steel	6.166	.0522	84.6	229.
Mild Steel	4.342	.0354	81.5	216.3
Steel 302	4.628	-.0001	- .216	-.5694
Steel 304	4.360	.0002	.459	1.190
Steel 316	4.388	.0001	.228	.592
Steel 347	4.236	.0002	.4725	1 .222

Table VII C

Washing Tank: Vapor Phase
Forty-Eight Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.378	.0009	1.936	7.28
Copper	4.598	.0091	21.0	24.8
Cor-Ten	5.510	.0749	136.0	179.3
Inconel	4.460	.0000	0.0	0.0
Monel	4.370	.0057	13.01	15.31
Nickel	4.394	.0100	22.78	26.75
Copper Steel	6.964	.1742	250.	338.5
Mild Steel	4.362	.0463	106.1	137.9
Steel 302	4.464	.0000	0.0	0.0
Steel 304	4.686	-.0001	-.2135	-.278
Steel 316	4.418	.0001	.2165	.2815
Steel 347	4.266	.0004	.9375	1.214

Table VII D

Washing Tank: Vapor Phase
Ninety-Six Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.568	.0011	2.41	4.65
Copper	4.746	.0127	35.7	20.7
Cor-Ten	5.941	.1627	274.	175.1
Inconel	4.380	.0000	0.0	0.0
Monel	4.728	.0010	23.25	13.94
Nickel	4.344	.0237	54.6	32.75
Copper Steel	5.698	.2995	526.	364.
Mild Steel	4.312	.1762	308.	276.9
Steel 302	4.628	-.0002	-.432	-.282
Steel 304	4.218	.0000	0.0	0.0
Steel 316	4.388	.0000	0.0	0.0
Steel 347	4.266	.0003	.695	.445

Table VII E

Washing Tank: Vapor Phase
One Hundred and Forty-Four Hour Exposure

Metal Specimen	Area, in^2	Loss in wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.434	.0011	2.48	3.125
Copper	4.598	.0333	72.5	28.76
Cor-Ten	6.178	.2615	422.5	191.0
Inconel	4.162	.0001	.240	.0984
Monel	4.134	.0213	51.6	20.2
Nickel	4.252	.0382	89.9	35.2
Copper Steel	6.950	.3870	650.	293.
Mild Steel	4.310	.2672	619.	273.8
Steel 302	4.496	.0002	.445	.195
Steel 304	4.280	-.0001	-.233	-.1013
Steel 316	4.306	.0000	0.0	0.0
Steel 347	4.358	.0002	.458	.1979

Table VII F

Washing Tank: Vapor Phase
Two Hundred and Four Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt,g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.374	.0004	.915	.8125
Copper	4.894	.0303	62.0	17.35
Cor-Ten	5.358	.3456	644.5	204.0
Inconel	4.306	.0001	.232	.0671
Monel	4.456	.0491	47.75	13.20
Nickel	4.288	.0205	110.0	30.4
Copper Steel	5.624	.3716	660.	210.5
Mild Steel	4.456	.2989	670.	209.0
Steel 302	4.464	.0000	0.0	0.0
Steel 304	4.280	.0000	0.0	0 .0
Steel 316	4.152	-.0003	-.7225	-.221
Steel 347	4.236	.0006	1.413	.430

Table VII G

Washing Tank: Vapor Phase
Three Hundred and Sixty Hour Exposure

Metal Specimen	Area, in^2	Loss in Wt, g.	Loss per Unit Area x 10^4	Corrosion Rate in ipy x 10^4
Aluminum	4.660	.0016	3.435	1.728
Copper	4.598	.0502	109.2	17.35
Cor-Ten	5.616	.7133	1270.00	228.2
Inconel	4.624	.0001	.2162	.03542
Monel	4.696	.0355	75.5	11.82
Nickel	4.528	.0721	159.2	24.93
Copper Steel	5.828	.7410	1272.	229.5
Mild Steel	4.310	.5800	1347.0	238.0
Steel 302	4.434	.0000	0.0	0.0
Steel 304	4.248	.0000	0.0	0.0
Steel 316	4.582	.0001	.221	.0383
Steel 347	4.236	.0006	1.419	.2446

Table VIII

Average Densities
and Thicknesses

Metal Specimen	Thickness, in	Density, g per in^3
Aluminum	.0320	48.3
Copper	.0320	153.4
Cor-Ten	.1340	135.7
Inconel	.0310	148.5
Monel	.0315	155.3
Nickel	.0305	155.3
Copper Steel	.1000	134.7
Mild Steel	.0404	137.8
Steel 302	.0370	138.6
Steel 304	.0300	140.1
Steel 316	.0345	140.4
Steel 347	.0330	141.0

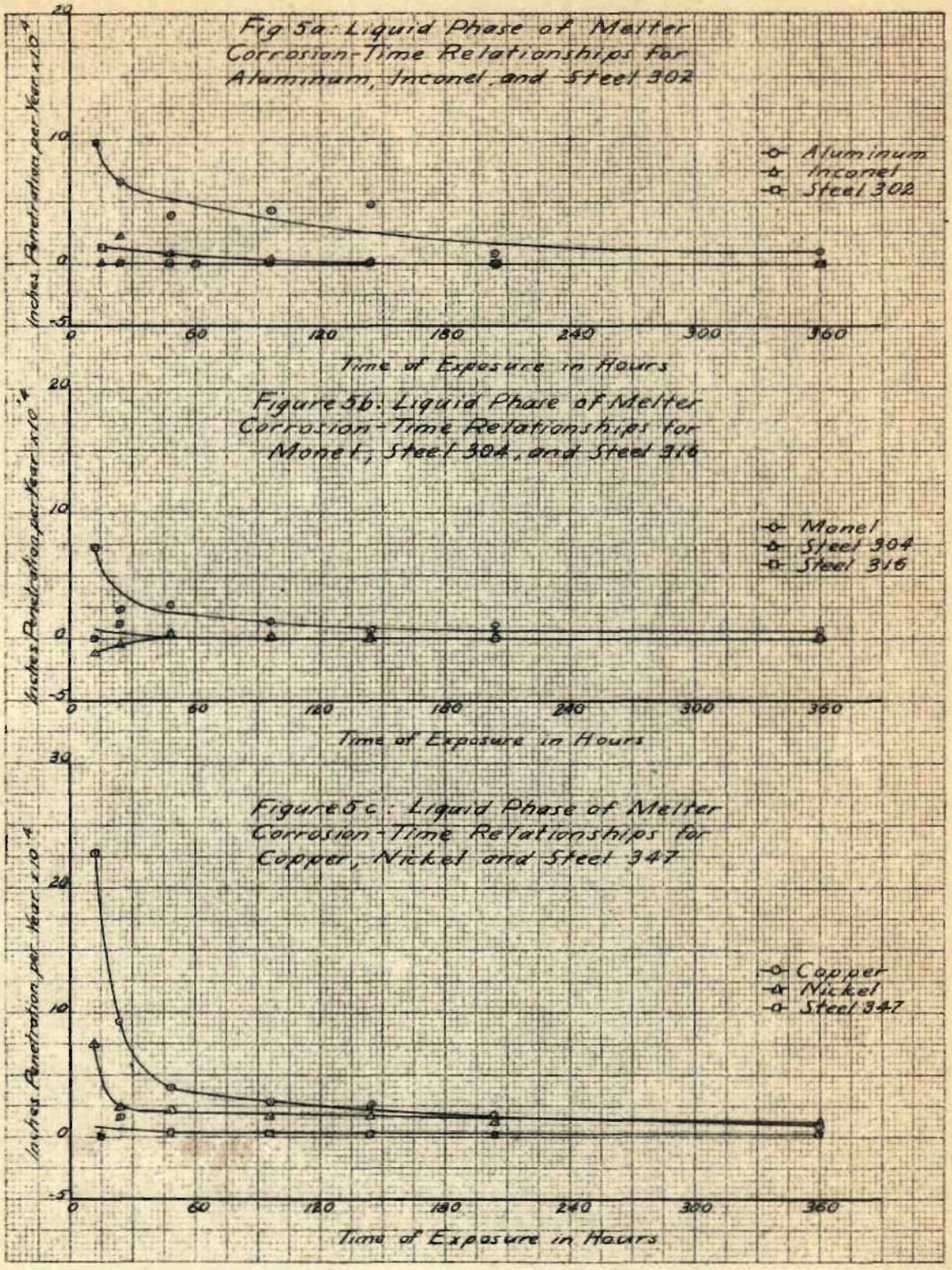


Fig 5a: Liquid Phase of Melter Corrosion-Time Relationships for Aluminum, Inconel and Steel 302

Figure 5b: Liquid Phase of Melter Corrosion-Time Relationships for Monel, Steel 304, and Steel 316

Figure 5c: Liquid Phase of Melter Corrosion-Time Relationships for Copper, Nickel and Steel 347

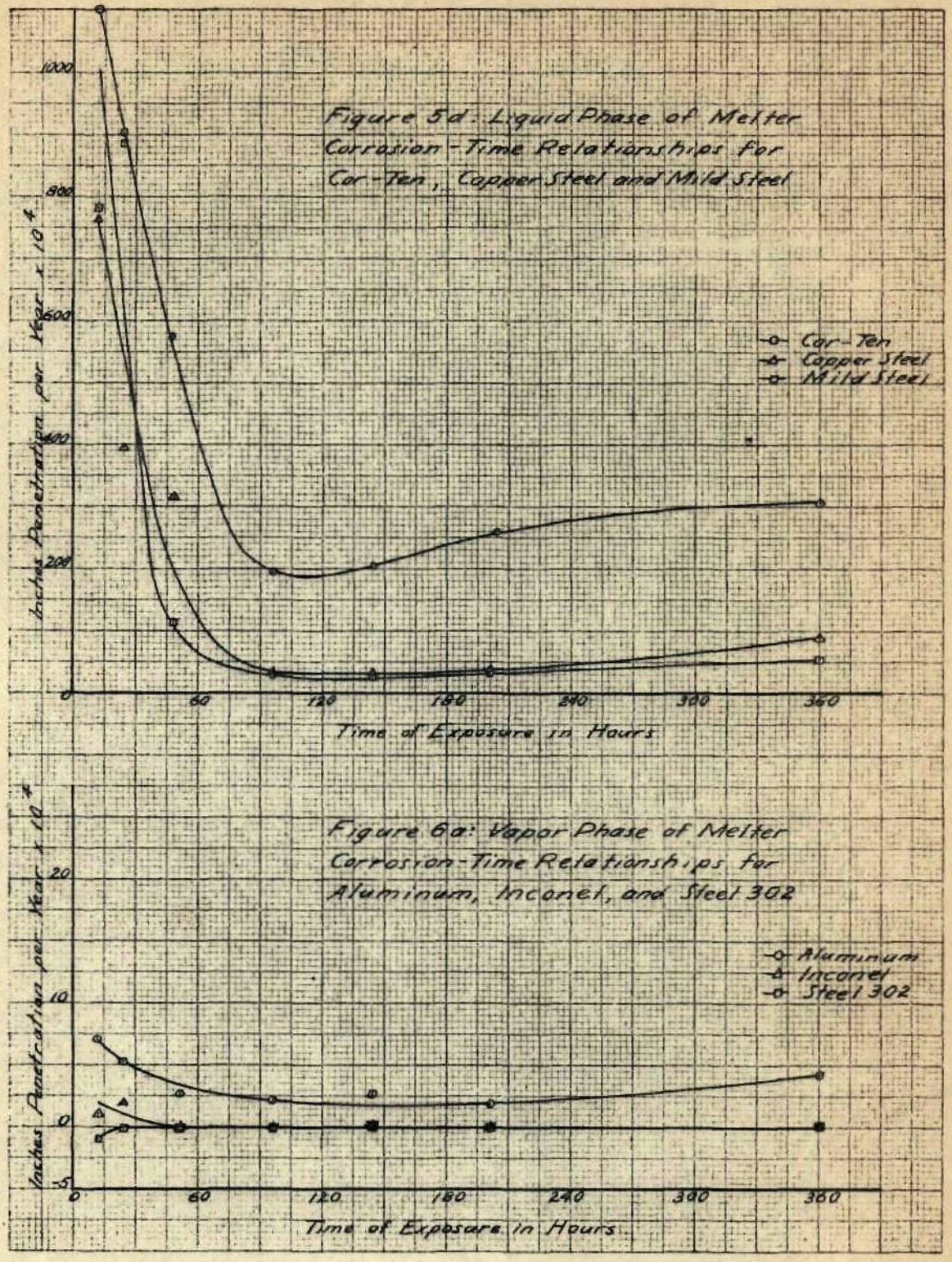


Figure 5d. Liquid Phase of Melter Corrosion-Time Relationships for Car-Ten, Copper Steel and Mild Steel
Car-Ten
Copper Steel
Mild Steel
Inches Penetration per Year x 10⁴
1000
800
600
400
200
0
60
120
180
240
300
360
Time of Exposure in Hours
Figure 6a: Vapor Phase of Melter Corrosion-Time Relationships for Aluminum, Inconel, and Steel 302
Aluminum
Inconel
Steel 302
Inches Penetration per Year x 10⁴
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours

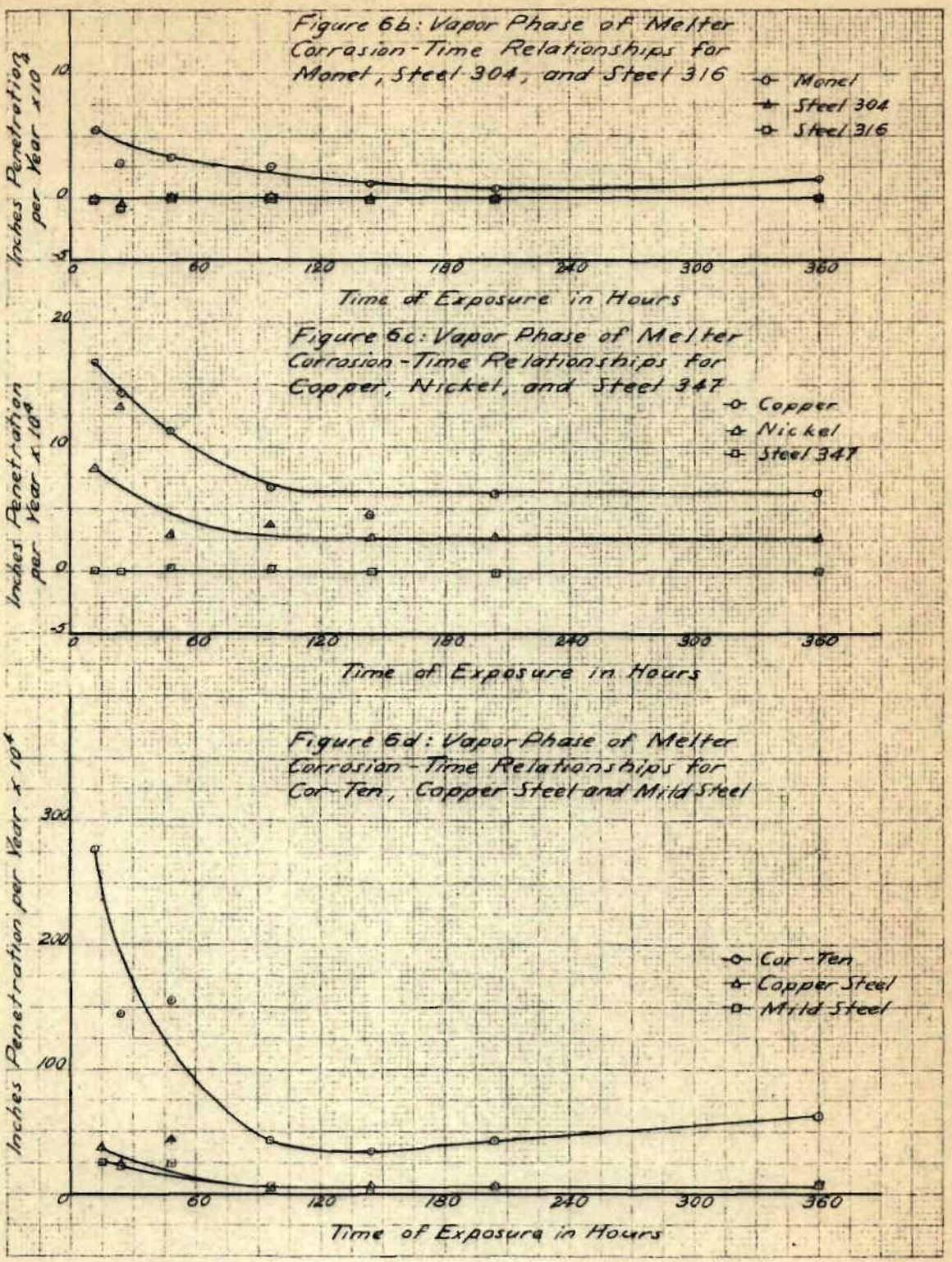
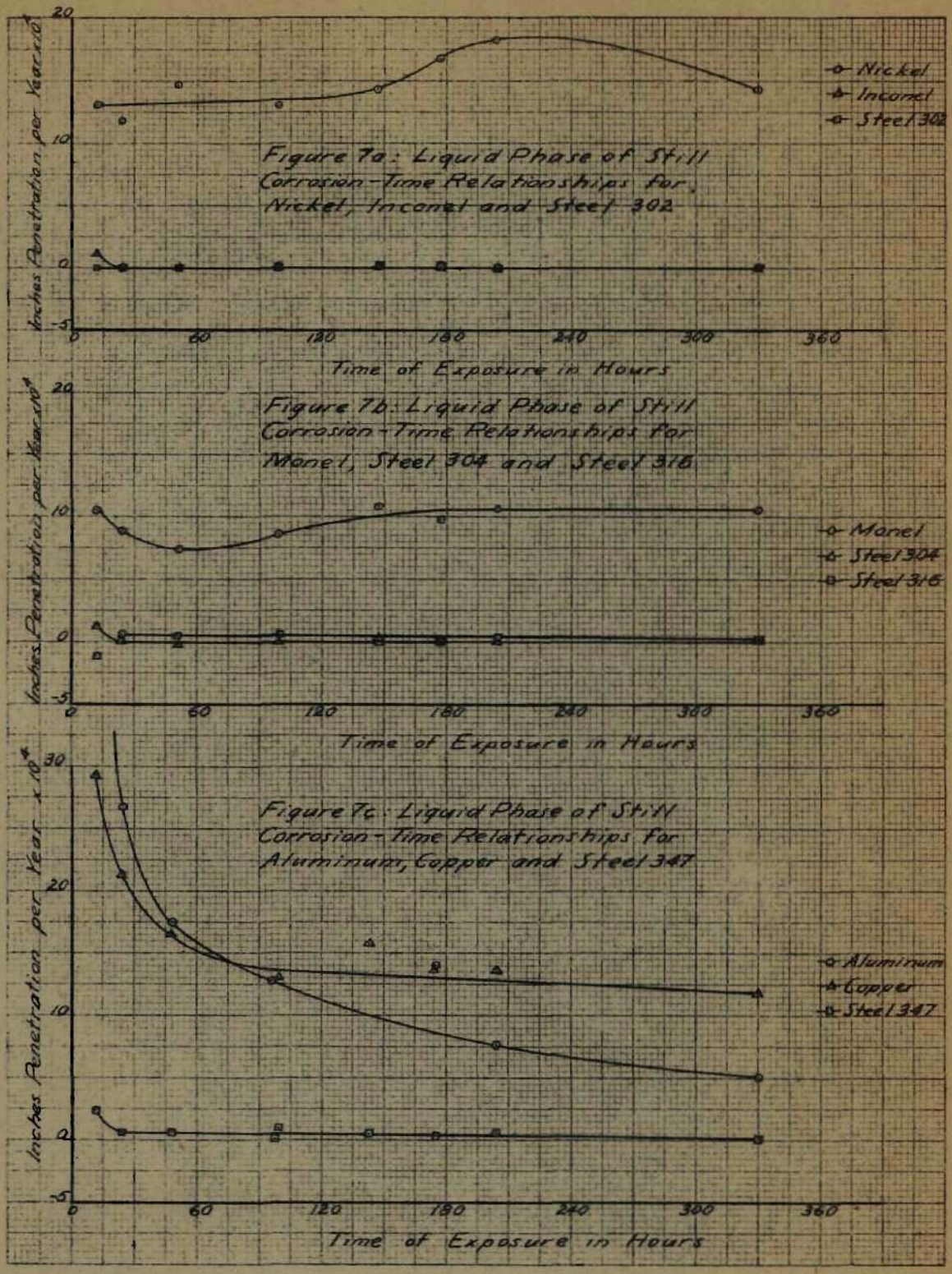


Figure 6b: Vapor Phase of Melter Corrosion-Time Relationships for Monel, Steel 304, and Steel 316
Inches Penetration per Year x 10
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Monel
Steel 304
Steel 316
Figure 6c: Vapor Phase of Melter Corrosion-Time Relationships for Copper, Nickel, and Steel 347
Inches Penetration per Year x 10⁴
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Copper
Nickel
Steel 347
Figure 6d: Vapor Phase of Melter Corrosion-Time Relationships for Cor-Ten, Copper Steel and Mild Steel
Inches Penetration per Year x 10⁴
300
200
100
0
60
120
180
240
300
360
Time of Exposure in Hours
Cor-Ten
Copper Steel
Mild Steel


Inches Penetration per Year x10⁴
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Nickel
Inconel
Steel 302
Figure 7a: Liquid Phase of Still Corrosion-Time Relationships for Nickel, Inconel and Steel 302
Inches Penetration per Year x10⁴
Monel
Steel 304
Steel 316
Figure 7b: Liquid Phase of Still Corrosion-Time Relationships for Monel, Steel 304 and Steel 316
Inches Penetration per Year x10⁴
30
Aluminum
Copper
Steel 347
Figure 7c: Liquid Phase of Still Corrosion-Time Relationships for Aluminum, Copper and Steel 347

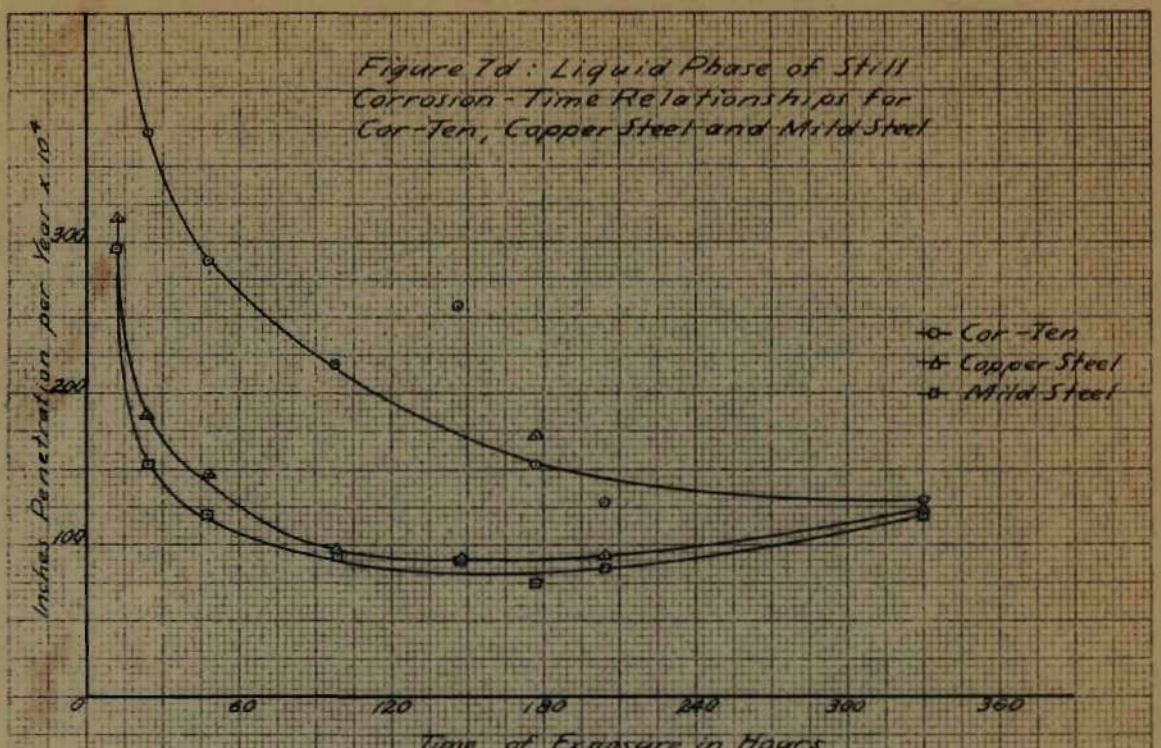


Figure 7d : Liquid Phase of Still
Corrosion - Time Relationships for
Cor-Ten, Copper Steel and Mild Steel
Inches Penetration per Year x 10⁴
300
200
100
0
60
120
180
240
300
360
Time of Exposure in Hours
Cor-Ten
Copper Steel
Mild Steel

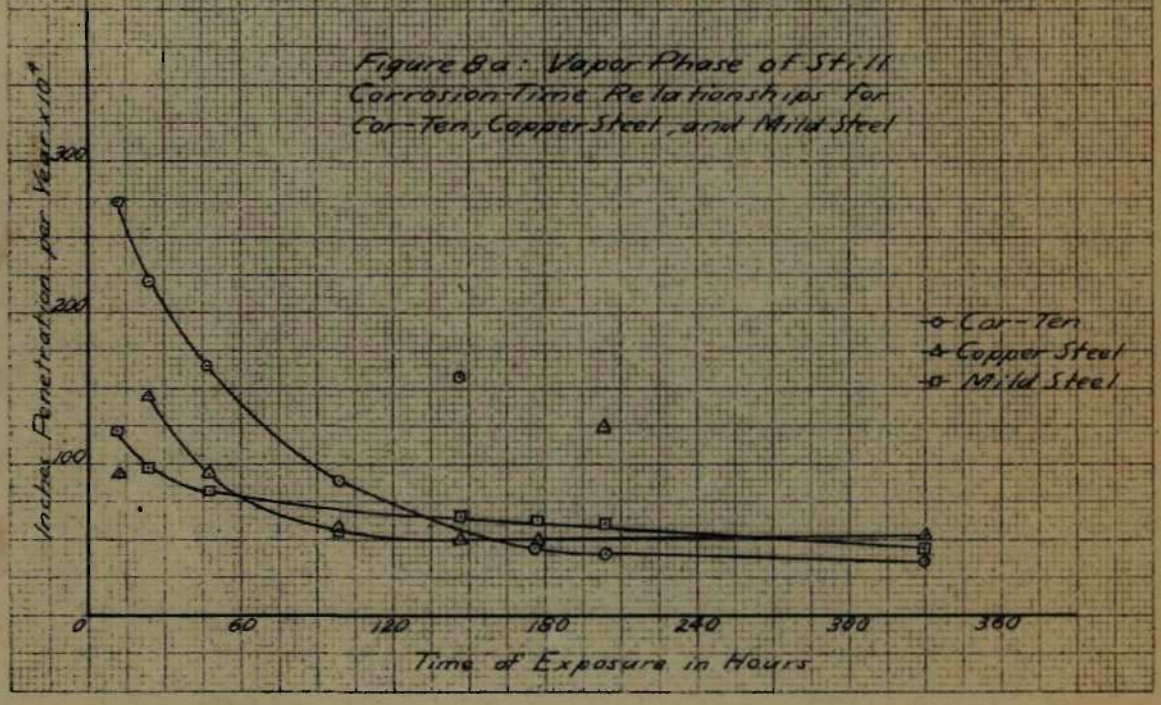


Figure 8a : Vapor Phase of Still
Corrosion-Time Relationships for
Cor-Ten, Copper Steel, and Mild Steel
Inches Penetration per Year x 10⁴
300
200
100
0
60
120
180
240
300
360
Time of Exposure in Hours
Cor-Ten
Copper Steel
Mild Steel

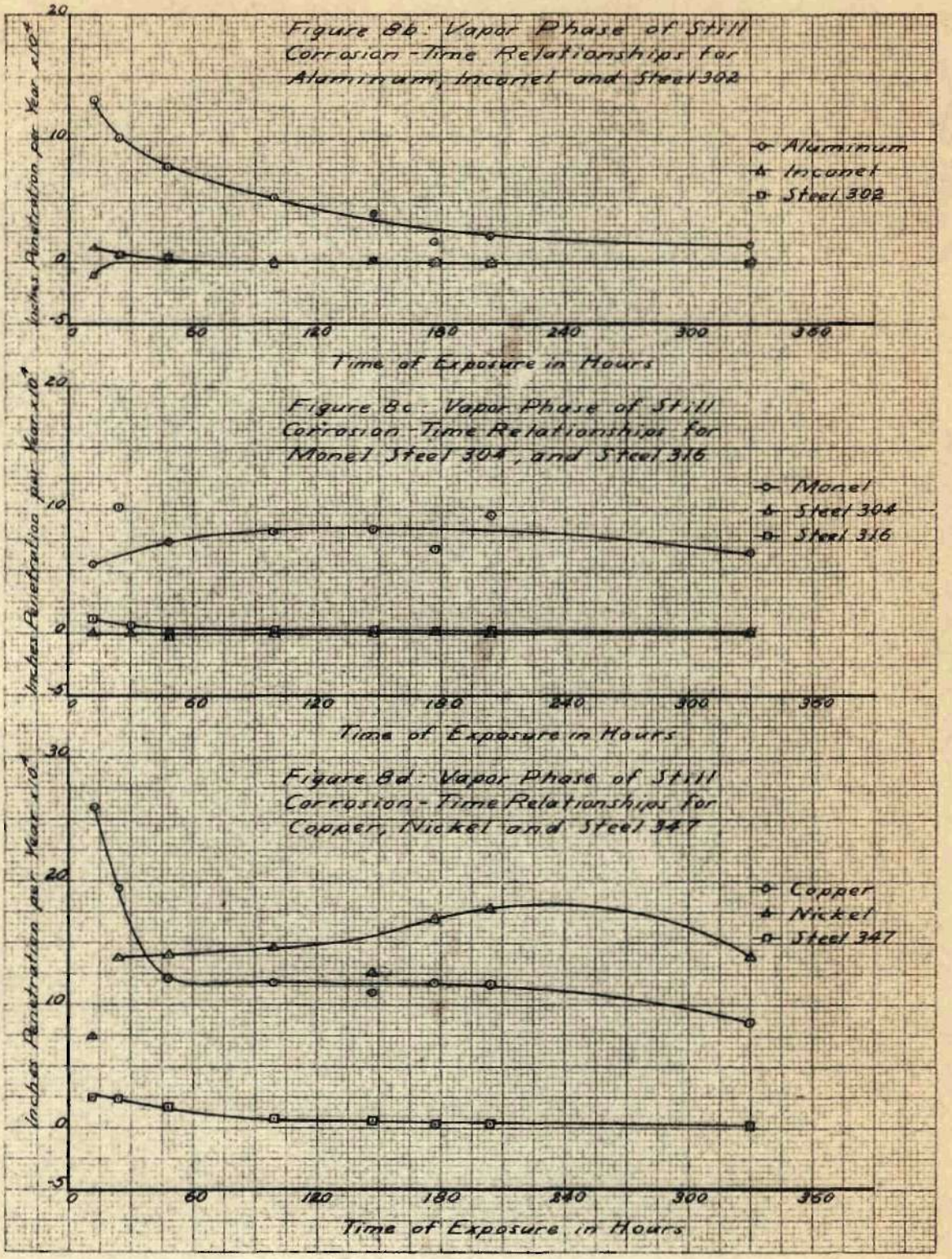


Figure 8b: Vapor Phase of Still Corrosion-Time Relationships for Aluminum, Inconel and Steel 302
Aluminum
Inconel
Steel 302
Inches Penetration per Year x10⁻⁴
Time of Exposure in Hours
Figure 8c: Vapor Phase of Still Corrosion-Time Relationships for Monel Steel 304, and Steel 316
Monel
Steel 304
Steel 316
Inches Penetration per Year x10⁻⁴
Time of Exposure in Hours
Figure 8d: Vapor Phase of Still Corrosion-Time Relationships for Copper, Nickel and Steel 347
Copper
Nickel
Steel 347
Inches Penetration per Year x10⁻⁴
Time of Exposure in Hours

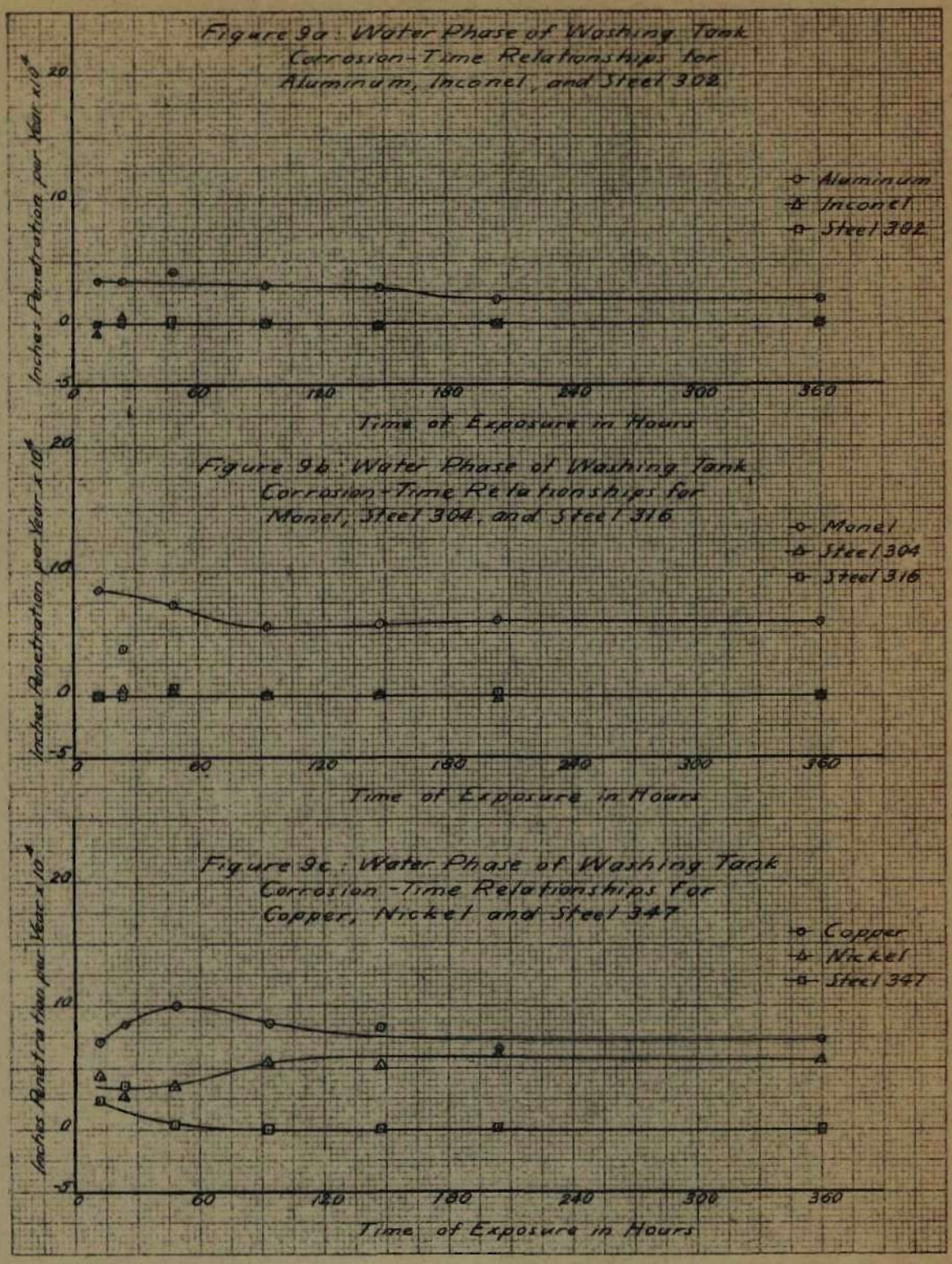


Figure 9a: Water Phase of Washing Tank
Corrosion-Time Relationships for
Aluminum, Inconel, and Steel 302
Inches Penetration per Year x 10⁻⁴
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Aluminum
Inconel
Steel 302
Figure 9b: Water Phase of Washing Tank
Corrosion-Time Relationships for
Monel, Steel 304, and Steel 316
Inches Penetration per Year x 10⁻⁴
Time of Exposure in Hours
Monel
Steel 304
Steel 316
Figure 9c: Water Phase of Washing Tank
Corrosion-Time Relationships for
Copper, Nickel and Steel 347
Inches Penetration per Year x 10⁻⁴
Time of Exposure in Hours
Copper
Nickel
Steel 347

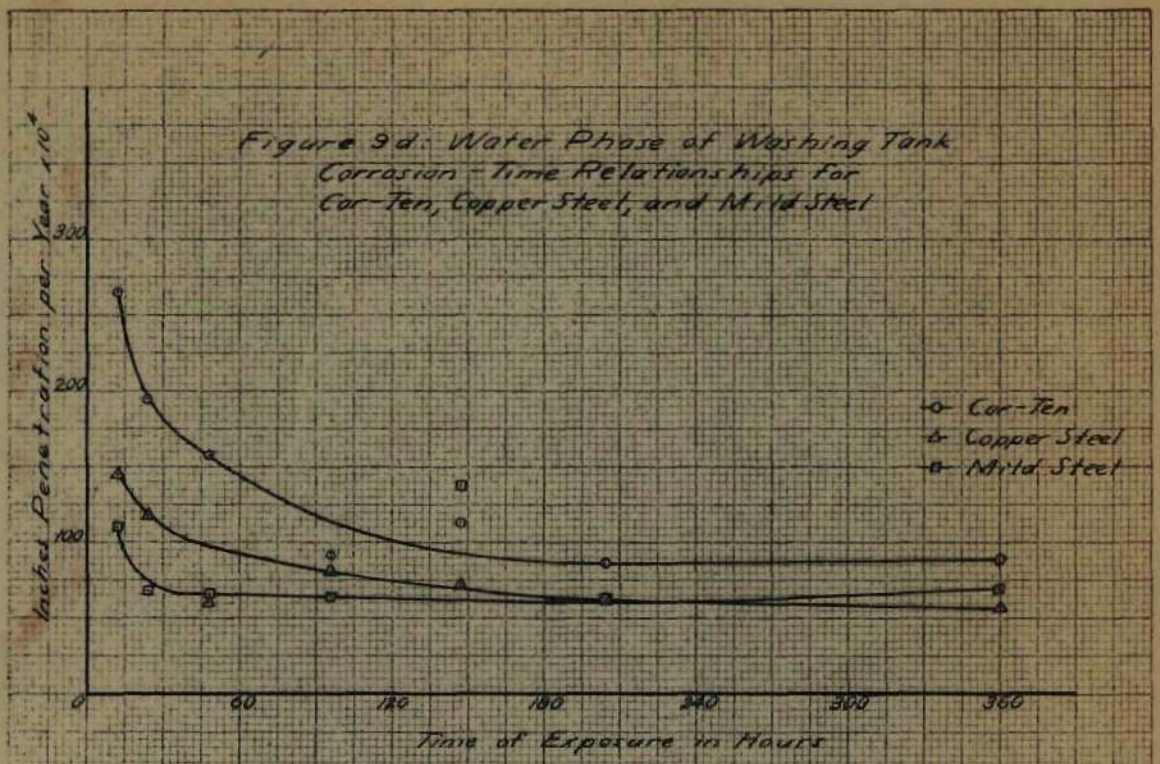


Figure 9d: Water Phase of Washing Tank
Corrosion - Time Relationships for
Cor-Ten, Copper Steel, and Mild Steel

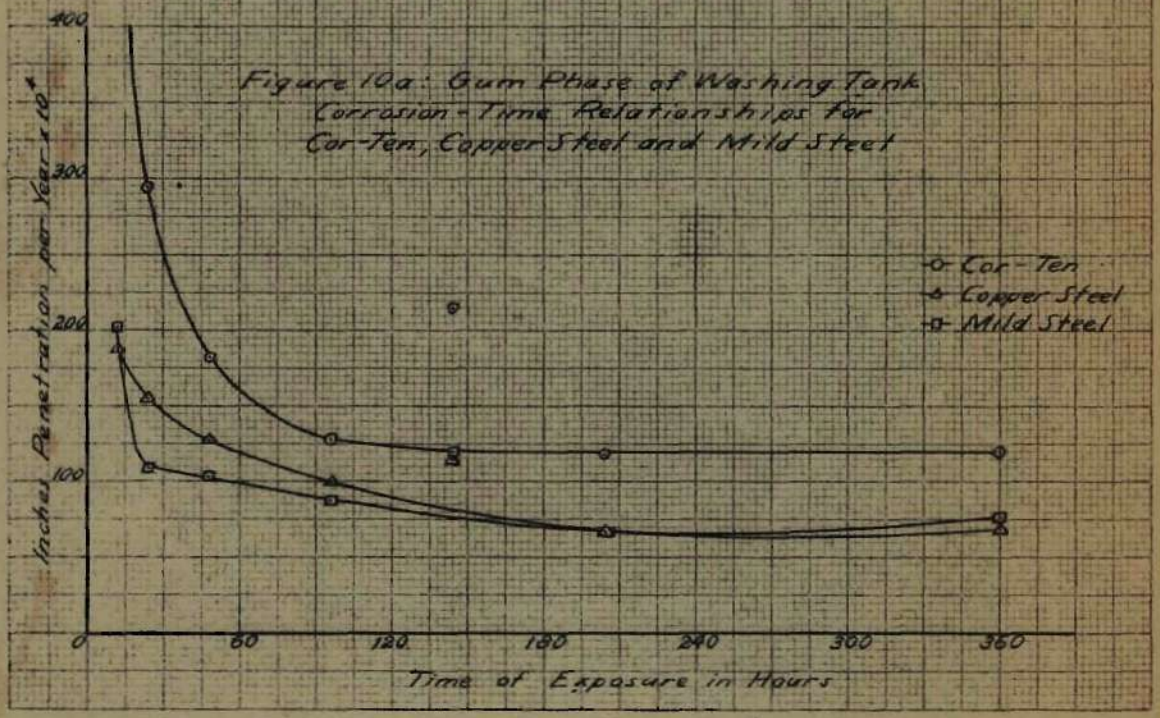


Figure 10a: Gum Phase of Washing Tank
Corrosion - Time Relationships for
Cor-Ten, Copper Steel and Mild Steel

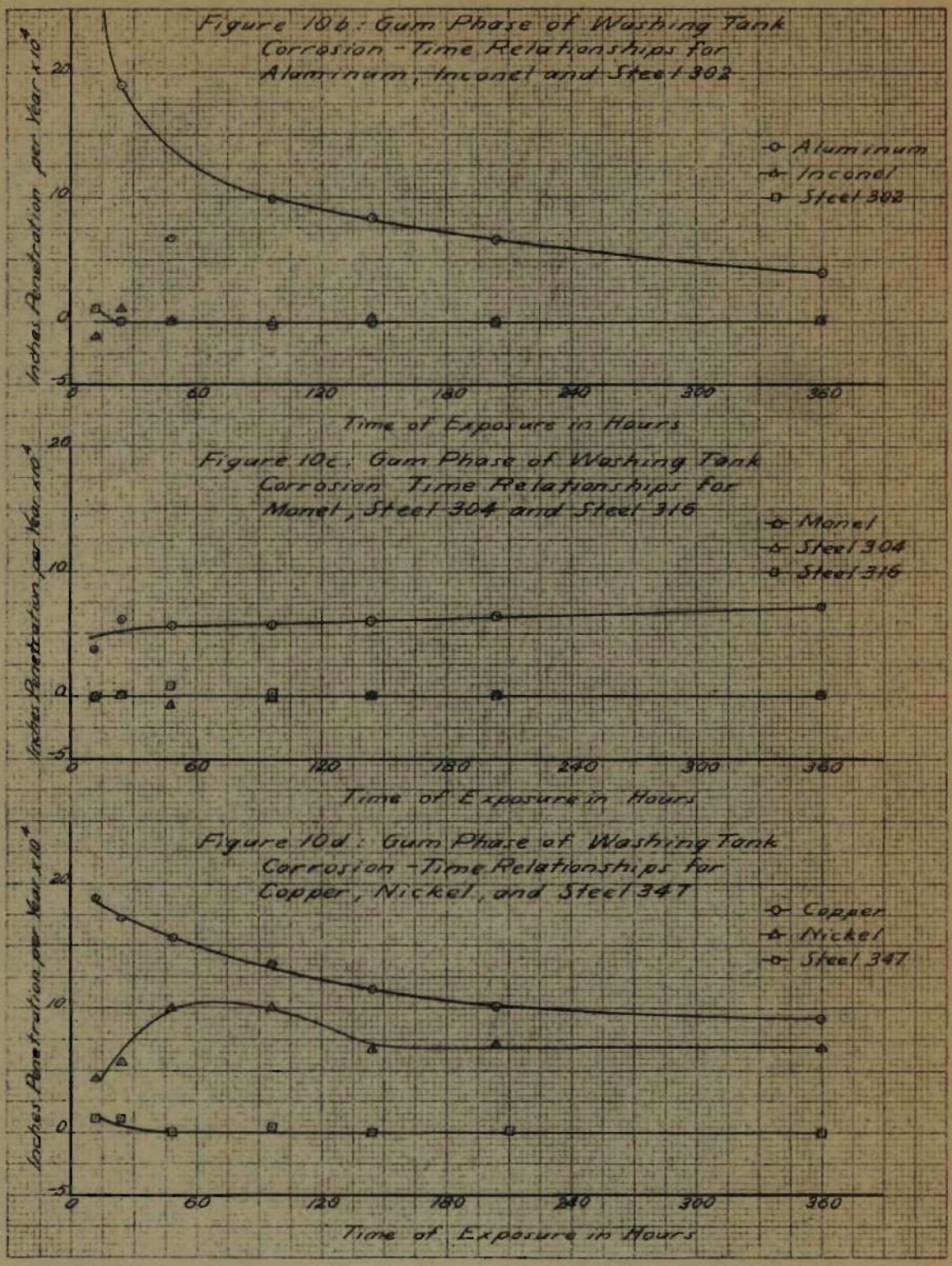


Figure 10b: Gum Phase of Washing Tank Corrosion - Time Relationships for Aluminum, Inconel and Steel 302
Inches Penetration per Year x10⁴
Aluminum
Inconel
Steel 302
Time of Exposure in Hours
Figure 10c: Gum Phase of Washing Tank Corrosion Time Relationships for Monel, Steel 304 and Steel 316
Inches Penetration per Year x10⁴
Monel
Steel 304
Steel 316
Time of Exposure in Hours
Figure 10d: Gum Phase of Washing Tank Corrosion - Time Relationships for Copper, Nickel, and Steel 347
Inches Penetration per Year x10⁴
Copper
Nickel
Steel 347
Time of Exposure in Hours

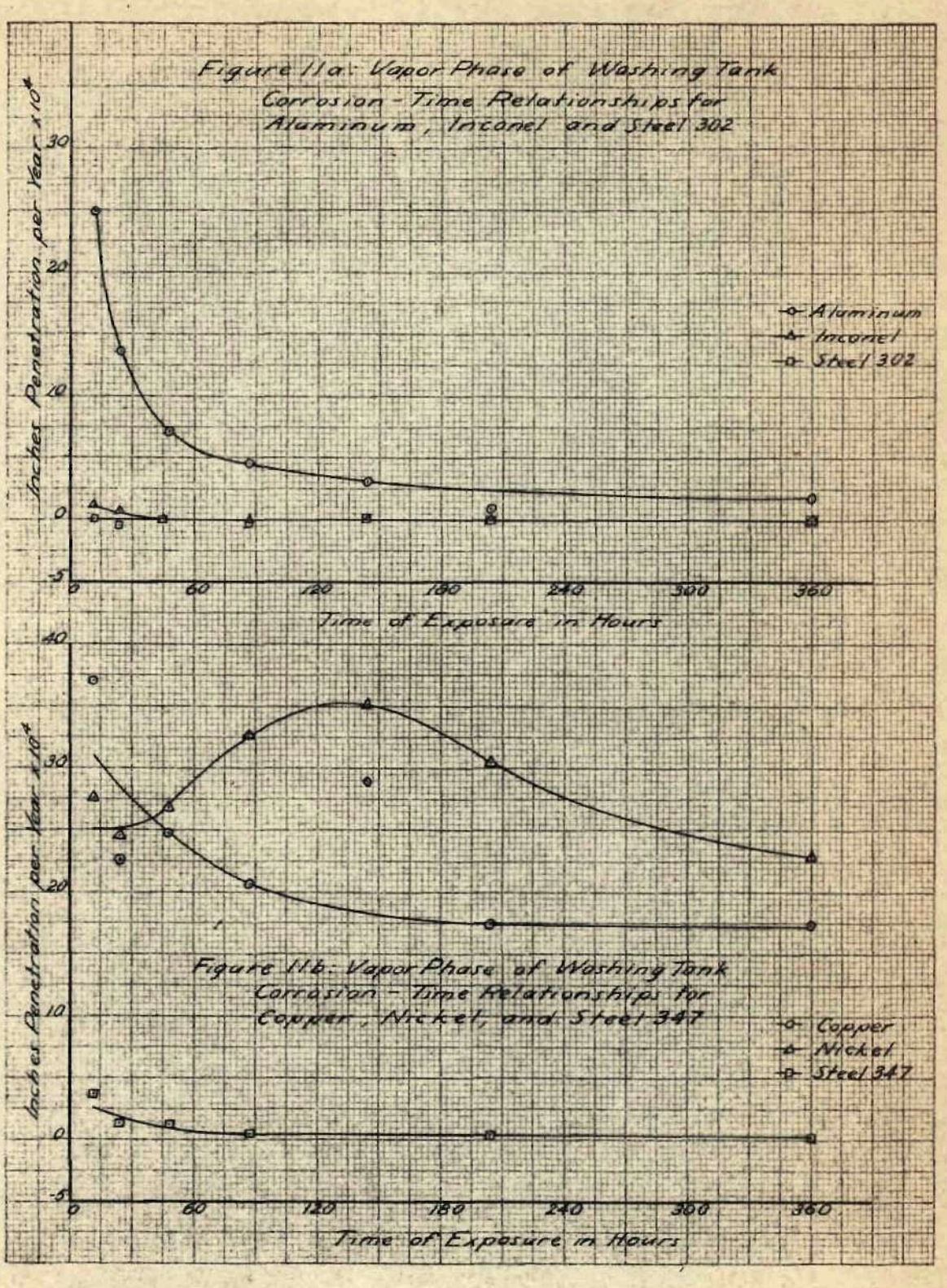


Figure IIa: Vapor Phase of Washing Tank
Corrosion - Time Relationships for
Aluminum, Inconel and Steel 302
Inches Penetration per Year x 10⁴
30
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Aluminum
Inconel
Steel 302
40
30
20
10
0
-5
Figure IIb: Vapor Phase of Washing Tank
Corrosion - Time Relationships for
Copper, Nickel, and Steel 347
Copper
Nickel
Steel 347

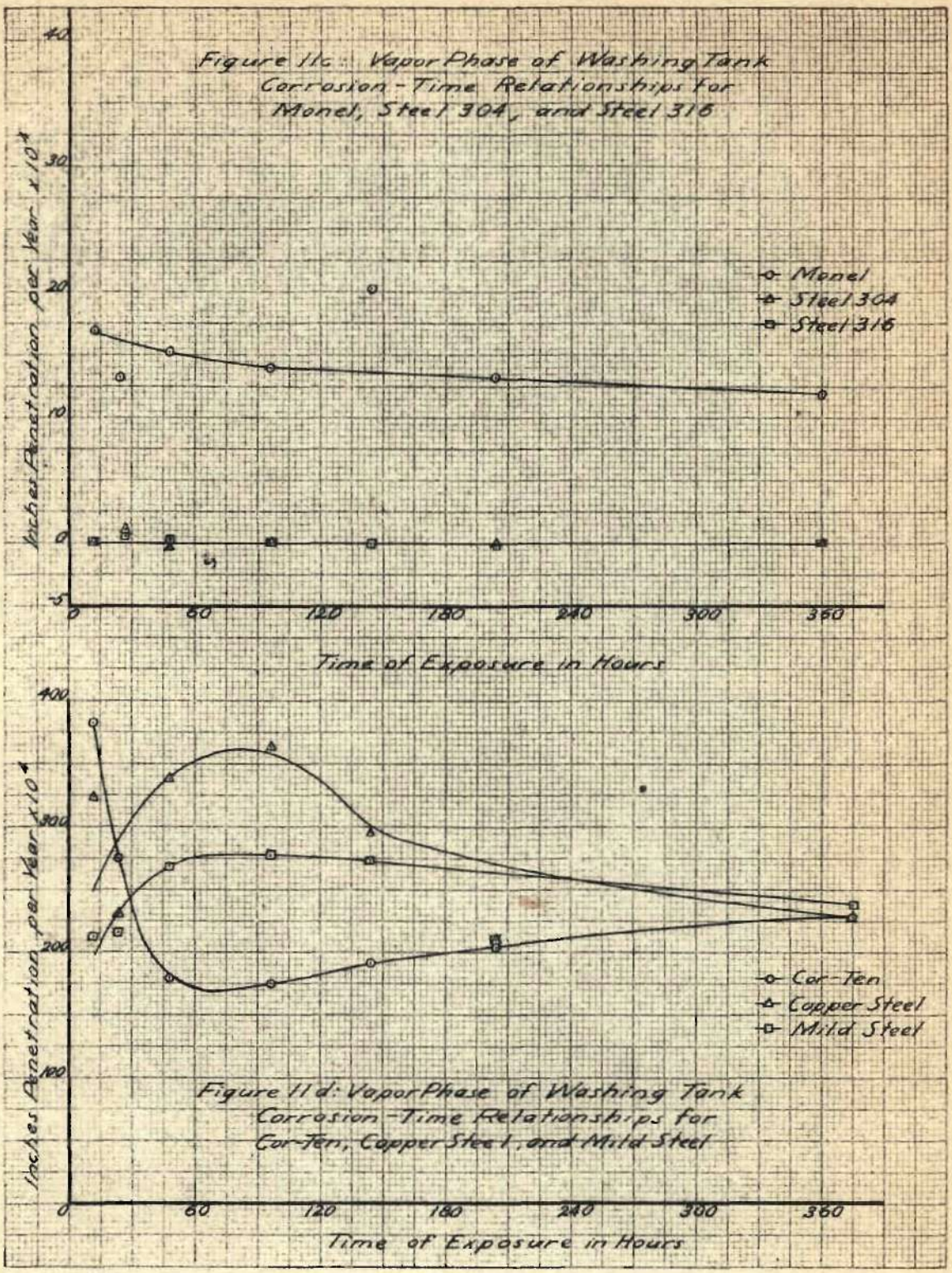


Figure IIc: Vapor Phase of Washing Tank
Corrosion-Time Relationships for
Monel, Steel 304, and Steel 316
Inches Penetration per Year x 10⁻⁴
40
30
20
10
0
-5
0
60
120
180
240
300
360
Time of Exposure in Hours
Monel
Steel 304
Steel 316
Figure IId: Vapor Phase of Washing Tank
Corrosion-Time Relationships for
Cor-Ten, Copper Steel, and Mild Steel
Inches Penetration per Year x 10⁻⁴
400
300
200
100
0
60
120
180
240
300
360
Time of Exposure in Hours
Cor-Ten
Copper Steel
Mild Steel

Table IX

Microscopic Examination for Pitting
Two Hundred Four and Three Hundred and Sixty Hour Exposure
Magnification: Ninety Diameters

Metal Specimen	Evidences of Pitting	Remarks
Aluminum	None	Uniform white film over the surface. This film was very adherent and hard to remove completely.
Copper	None	Uniform corrosion over entire surface. A few discolorations in the vapor phases of the melter, washing tank, and still.
Cor-Ten-	None	Uniform corrosion. Black amorphous film formed in the vapor phases which was easily brushed off, leaving a clean bright surface. Surfaces in liquid phases were untarnished.
Inconel	None	No change in physical appearance.
Monel	None	Corrosion uniform. Slight darkening of surface evident; increased with increasing periods of exposure.
Nickel	None	Corrosion uniform. Slight darkening of surface evident; increased with increasing periods of exposure.
Copper Steel	None	Uniform corrosion. Black amorphous film formed in the vapor phases which was easily removed, leaving a clean bright surface. Surfaces in liquid phases were untarnished.
Mild Steel	None	While no evidence of pitting was noticed, surface showed severe, localized attack. Products were hard to remove.
Steel 302	None	No change in physical appearance.
Steel 304	None	No change in physical appearance.
Steel 316-	None	No change in physical appearance.
Steel 347	None	No change in physical appearance.

Figure 12: Original Sample of Mild Steel

Magnification: Forty Diameters

Figure 13: Mild Steel after

Three Hundred and Sixty Hour Exposure

Magnification: Forty Diameters

DISCUSSION OF RESULTS

In interpreting the results from this series of corrosion tests, it must be remembered that the data are specific and must not be applied too generally. The purpose of the studies was to find the best material or materials for construction of the various units: the melter, the washing tank, and the still, in the turpentine-gum processing plant. Standard corrosion tests on all the metals and alloys tested here have surely been run, so further repetition would have been pointless. Further, materials found to be most resistant to corrosion under the conditions encountered here may well be less resistant to corrosion under the conditions encountered in some other process where the corrosive media are different in nature and the operating conditions are changed--that is, different temperatures and pressures.

An idea of the resistance to corrosion of any particular sample in any specific phase may best be had by examining Figures 5 to 11 inclusive. It will be noted that the entire series of the rate of corrosion-time relationships may be classified into three general categories.

The first type, illustrated by Figure 7c for aluminum, is perhaps the most common. This type represents a high initial corrosion rate;but as the exposure increases, the rate drops off due to a protective film formation. After the film formation is complete, the rate of corrosion might be

constant at a certain value, or cease altogether. In the former case, the curve would level off into a straight line at a definite value of perhaps five inches penetration per year. In the latter case, the curve would approach zero inches penetration per year as an asymptote.

The second type relation is practically reversed from the first. The characterizing curve of a low initial but increasing corrosion rate with asymptotic approach to same value well above zero inches penetration is the curve that would result if a curve of the first class were turned upside down. It is approximated most nearly by the corrosion rate vs. time relation for monel in Figure 10c. This type is probably due to the presence of an oxide film already formed before the specimen is subjected to test. The stability of this film may vary. If the stability were slight, the slope of the initial portion of the curve would approach infinity, and if it were very stable, the slope would be zero, and no corrosion would result. Penetration of the film usually occurs, and corrosion increases at an accelerated rate until a second protective film of a specific nature is formed. (By "specific" is meant the protective film formed in a particular corrosive media.) With this formation the curve again levels off as in type one.

The third type is that encountered when the corrosion rate is constant throughout. In this case, a straight line results when the rate is plotted against time of exposure.

In this type no film formation is likely if the constant value of rate of rorrosion lies above zero inches penetration per year. Whatever resistance there may be must lie in the Chemical or physical nature of the metal or alloy. When the constant value of rate of corrosion lies at the zero value, the resistance may be due either to the metal, as mentioned previously, or the presence of an impenetrable protective film formed before the specimen is subjected to test. An example of this type may be found in Figure 6A for inconel. (The initial rise in the curve represents a weight loss of one tenth of a milligram on a twelve hour exposure. This is out of the limit of experimental accuracy. On the longer periods of exposure, a slight variation of this sort is minimized.)

Of the metals tested, aluminum, copper, cor-ten, copper bearing low carbon steel, and mild steel seem to belong to class one in most of the phases. The USS 18-8 stainless steels, types 302, 304, 316 and 347, as well as inconel, are of class three. In class two, the mild steel, monel, and nickel may be placed in certain cases. (See figures 11d, 8c, and 9c respectively) A number of the relations, however, show characteristics of each of the three types. The best method of analysis in such cases, it seems to me, is to break down the curves into sections and consider the portions separately.

As an example of such analysis, consider the relation

for nickel in Figure 7a. The initial portion of the curve is essentially one of type three; a straight line denoting no film formation or at least corrosion of a uniform rate. A film of a sort must have been present, however, for the rise would represent complete destruction or penetration of the film with subsequent increased rate of corrosion. The formation of the second "specific" protective film is represented at the curve's maximum. The rate then decreases and will probably level off to some constant value on increased periods of exposure.

The results are reported in "inches penetration per year" abbreviated "ipy". Expressing results in this fashion gives one an idea of the expected life of the test piece if the rate of corrosion by uniform solution during a particular exposure were continued twenty-four hours a day for three hundred and sixty-five days a year. Additional relations of loss of weight per unit area vs. time might have been plotted, but the results are not as applicable or as easily grasped.

The calculation of inches penetration per year is a simple one:

$$ipy = \frac{(365)\,(24)\,(W.L.)}{(T)\,(A)\,(D)}$$

T is the time of exposure in hours.

W. L. is the loss in weight in grams.

A is the area of the sample is square inches.

D is the density of the sample in grams per cubic inch.

This method of evaluation for corrosion losses seems justified in this case for the mechanism of the corrosion was uniform solution. There was no evidence of pitting in any instance as is shown by Figures 12 and 13. If pitting had occurred, it was most likely to be here, for most of the mild steel samples showed areas of severe local attack.

On examining the tabulated data, as well as the corrosion rate vs. time relations, the reader may be surprised to find negative values of corrosion rates and losses recorded. This is an impossible situation. It will be noted on closer examination, however, that the magnitude of the weight increase during exposure accounting for the negative figure is of the order of one-tenth to two-tenths of one milligram. This might easily represent the error in weighing a given sample two different times. The error may be due also to small particles of dust that may have collected on the sample after the final washing was made. One would expect similar errors of positive values. The negative values were calculated and recorded in order that the experimental errors of this sort be made to cancel when the results were plotted.

SUMMARY

Further study might be made on this problem. The field of metals and alloys to be tested might be enlarged to include metal-sprayed samples. In this time of emergency, most of the materials tested in this series are unavailable. Metal spraying might be the solution. By this means, some comparatively cheap base metal could be coated or sprayed with a more expensive but, at the same time, more corrosion-resistant material. The metal coating would have to be uniform and thick enough to prevent penetration by handling, for, once penetrated, the rate of attack would be greater than for either taken singly due to contact corrosion.

Further improvement and greater accuracy in predictions would result from running a single period of exposure numerous times. Mears and Daniels[11], on the basis of research data obtained at Cambridge University, had derived an empirical formula for calculating the probable error in corrosion research. This relation is:

$$H = \frac{.67\ S}{\sqrt{n}} = \frac{.67\sqrt{\frac{D^2}{n-1}}}{\sqrt{n}}$$

H is the probable error.

S is the estimated standard deviation.

D^2 is the summation of the squares of the deviations of each experimental result from the mean of all results.

n is the number of times a particular run is made.

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[11] Mears, R.B., and H.E. Daniels, "Errors in Corrosion Research" American Electrochemical Society Transactions.(preprint 16) pp. 374-390, 1935.

It is apparent upon examination that the probable error may be decreased in one of two ways: by increased refinement of experimental methods and hence more accurate results, or, by an increase in the number of times a certain run or experiment is performed. A fair percentage of the errors in experimental work are unavoidable; the logical thing would be to perform the experiment a greater number of times.

This duplication is, of course, time consuming. It was originally intended to duplicate all runs in each of the seven existing phases. The time required for this duplication was so excessive that duplications were made only on the first four exposure periods--twelve, twenty-four, forty-eight, and ninety-six hours. Since seven samples were run for each exposure period, one in each phase, it seemed logical that serious errors could be detected when the plot of rate of corrosion vs. time was made, thus decreasing the probable error. In addition, points which fall definitely out of the range of probable values for any particular series can also be seen on the same plot. These plots are shown in Figures 1 to 7 inclusive.

A great improvement would result if the tests were run in some large scale processing plant. A number of test spools such as those described by Searle and La Que[12] could

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[12] Searle, H. E., and F. L. La Que, "Corrosion Testing Methods", American Society for Testing Materials, Vol. 35, Part 2, pp. 249-260, 1935.

be mounted in each unit and removed at longer intervals--perhaps every six months. The results on these increased periods in actual plant operation would be a truer index of corrosion resistance than any that might be obtained on a laboratory scale.

CONCLUSIONS

Of the twelve metals tested, the overall corrosion resistance may be expressed in the following order: USS 18-8 stainless steel 304, USS 18-8 stainless steel 302, inconel, U. S. 18-8 stainless steel 316, USS 18-8 stainless steel 347, aluminum, monel, nickel, copper, copper bearing low carbon steel, mild steel, and cor-ten. Variations from one phase to another in the degree of resistance may be seen by examining the curves in Figures 5 to 11.

The differences between the resistance to corrosion of each of the stainless steels and inconel is negligible in almost every case. Any one of these would prove entirely satisfactory from this standpoint.

Specific corrosion resistance is not the only factor that must be considered in choosing a material for the fabrication of the different units. Economic balances must be set up for each of the metals. In this balance,the initial cost of the metal must be considered, the expected life under the conditions of use, and the effect of the corroded metal products on the finished turpentine and rosin. It might be added that some metal salts have a deteriorating effect on the rosin. Comparatively minute concentrations of iron salts may lower the grade of the rosin produced by severl letters. When all these factors are considered, the most economical metal for use will be known.

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